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Treball Final de Grau

Evaluation, valorization and treatment strategies for the residues of wine cellars: a case of study

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En primer lloc, agrair a la meva tutora Carme Sans Mazon per haver dedicat temps a aquest treball i per tota l'ajuda i paciència que ha tingut durant aquests mesos.

També, donar les gràcies al Mas Santmartí de Serrahïma per haver-me facilitat informació sobre el procés de producció. Per altra banda, agrair al Celler Les Acàcies per haver-me obert les portes i deixat veure el funcionament d'un celler.

No vull oblidar-me del suport de la meva família que ha estat sempre recolzant-me i aguantant-me en els moments més complicats del treball i, en general, de la carrera. Gràcies a la seva insistència he pogut arriscar-me a tirar un tema de Treball de Fi de Grau que em motiva i m'apassiona.

Finalment, agrair els meus amics i amigues que han estat aguantat i compartint els maldecaps, les frustracions i les alegries que comporta dur a terme un treball de fi de grau.

CONTENTS

SUMMARY

Wine is a beverage obtained from grapes through the fermentation of the must. Fermentation is caused by the metabolic action of yeast, which converts the sugars in the fruit into ethyl alcohol and carbon dioxide. During the winemaking process, various residues and by-products are produced. The three main vinification waste products are grape pruning, grape pomace, and wine lees.

This study can be divided into two parts: a bibliographic research section and an experimental section. Through the bibliographic research, information has been gathered about the different by-products generated by the winery industry and various methods for valorising winery by-products.

After acquiring knowledge in this field, composting has been selected as the preferred method for managing and valorising solid wastes from a winery cellar. This treatment has been specifically tailored for winery cellars of small to medium sizes. The implementation of this treatment will take place in a cellar named Mas Sanmartí de Serrahïma, which is situated in Pla del Bages. The composting facility will handle 22 tonnes of winery residues, comprising of grape pruning, grape pomace, and wine lees. To ensure effective composting, a semi-open system with six turned windrows will be employed. These windrows will be sheltered by a permeable cover and will also feature a leachate recovery system. Additionally, a small cover will be constructed to facilitate the curing phase and storage of the final product.

Ultimately, with an investment of approximately 100,000 €, a composting plant can be constructed, and winery waste can be valorised to obtain a valuable product that can be effectively used within the vineyard.

Keywords: grape pomace, wine lees, pruning stalks, winery by-products, waste valorisation, extraction techniques, composting treatment.

RESUM

El vi és una beguda que s'obté a partir de la fermentació del most. La fermentació és produïda per l'acció metabòlica dels llevats que transformen els sucres del raïm en alcohol etílic i diòxid de carboni. Durant el procés de vinificació es generen diversos residus i subproductes. Els tres residus principals de la producció de vi són la poda de les vinyes, l'orujo de vi i les vinasses.

Aquest estudi es pot dividir en dues parts: una secció de recerca bibliogràfica i una secció experimental. A través de la recerca bibliogràfica, s'ha recopilat informació sobre els diferents subproductes generats per la indústria vinícola i els diversos mètodes per valoritzar els subproductes.

Després d'haver adquirit coneixement en aquest camp, s'ha seleccionat el compostatge com a mètode preferit per gestionar i valoritzar els residus sòlids d'una celler vinícola. Aquest tractament està especialment dissenyat per a cellers vinícoles de mida petita o mitjana. La implementació d'aquest tractament tindrà lloc en un celler anomenat Mas Sanmartí de Serrahïma, situat al Pla del Bages. La instal·lació de compostatge gestionarà 22 tones de residus vinícoles, que inclouen la poda de les vinyes, l'orujo de vi i les vinasses del raïm. Per garantir un compostatge eficaç, s'ha apostat per un sistema semiobert amb sis piles de compostatge. Aquestes piles estaran protegides per una coberta permeable i també tindran un sistema de recuperació de lixiviats. A més, es construirà una petita coberta per facilitar la fase de maduració i l'emmagatzematge del producte final.

Finalment, amb una inversió d'aproximadament 100.000 €, es pot construir una planta de compostatge i valoritzar els residus vinícoles per obtenir un producte valuós que es pugui utilitzar eficaçment dins de la vinya.

Paraules clau: orujo de vi, vinasses, restes de poda, subproductes, valorització de residus, tècniques d'extracció, compostatge.

SUSTAINABLE DEVELOPMENT GOALS

The Sustainable Development Goals (SDGs) encompass 17 goals that address the social, economic, and environmental challenges involved in sustainable development for humanity. These goals can be categorized into five broad areas, known as the 5Ps, which interact with one another to ensure sustainable development: People, Prosperity, Planet, Peace, and Partnership.

Throughout the development of this project, all 5Ps have been taken into consideration. The goals that have had the most significant influence are SGD 12: Responsible consumption and production and SGD 13: Climate action. The connection between these two goals and the project becomes apparent when various alternative methods of valorising waste products from the vinification process are explained. By valorising these waste products, other materials that would have been used to fulfil a specific function can be substituted. This not only serves a useful purpose but also prevents and reduces environmental impact and climate change, underscoring the importance of these goals.

Another important group represented in this project is Prosperity, which aims to achieve SGD 7: Affordable and clean energy, SGD 8: Decent work and economic growth, and SGD 9: Industry innovation and infrastructure. The project focuses on modern extraction techniques for extracting biocomponents. These green technologies consume less energy and promote technological innovation. Furthermore, the chosen method of final treatment is the most affordable and energy-efficient technique available. In terms of SGD 8, inclusive and sustainable economic growth is achieved through the high demand for soil fertilizers. Composting vinification wastes can create job opportunities and contribute to the economic growth of the wine sector.

1. INTRODUCTION

For a long time ago, winemaking has held a traditional and historical significance in Catalonia. It represents the third most important sector in agro-alimentary Catalan industry (Mínguez et al., 2011). The wine sector in Catalonia is known for its strong and competitive structure, boasting over 17,000 winegrowers, more than 500 wineries bottlers, and employing over 22,000 people (Minguez, et al., 2011).

1.1. BAGES WINE ACTIVITY

The Bages region has a long history of having numerous vineyards and producing excellent wines. Its tradition of winemaking dates back as far as its recorded history. In the 10th century, there were historical documents that confirmed the existence and prominence of vineyard cultivation and wine production in the region (DOP Pla de Bages, 2022). Geographically, the Bages region is situated in the eastern part of the Ebre River Basin, nestled between the Catalánides and the Pyrenees. The location, type of soil, and climate all play a significant role in the winemaking process and ultimately influence the sensory characteristics of the wine.

1.2. VINIFICATION PROCESS AND CIRCULAR ECONOMY

Wine is a beverage obtained from grapes by fermentation of the must. Fermentation is produced by metabolic action of the yeast that transforms the sugars of the fruit in ethyl alcohol and carbon dioxide. The natural sugars and acids found in grapes provide everything necessary for this fermentation process to take place (Mínguez et al., 2011). The vinification process for producing red and white wines differs slightly. The type of wine being produced determines the specific steps involved. Figure 1 shows a diagram of both processes, with the yellow section representing white wine vinification and the red section representing red wine vinification.

The main difference between the two processes is that for white wines the pressing is done before the fermentation. In other words, the grape skins are removed before fermentation. In contrast, red wine is coloury due to the tannins form the skin and pips which, through maceration, provides its tonality.

Figure 1 also shows the wastes produced in each stage. All these wastes: grape stalks, grape pomace, inorganic wastes and wine lees need a treatment to reduce the organic charge and promote a circular economy reducing the environmental impact.

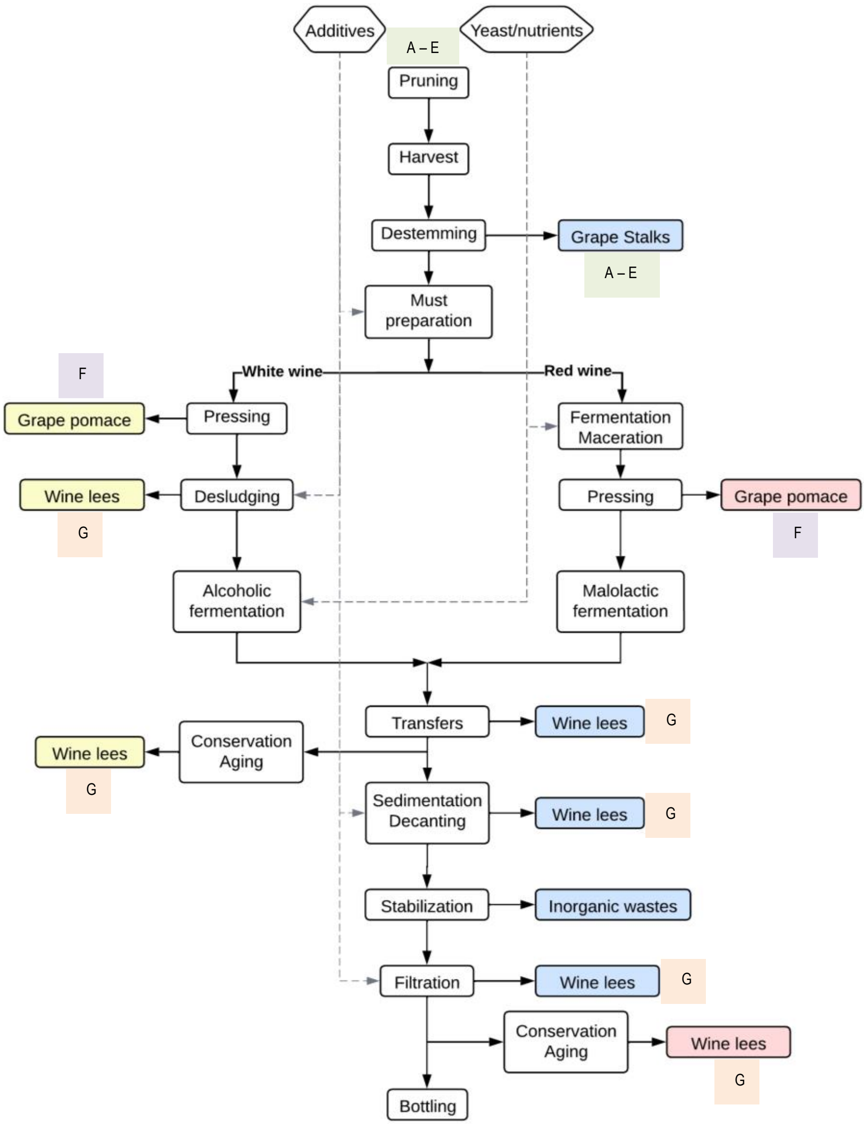

Figure 1. Vinification process diagram. Source: own elaboration adapted from Mínguez et al., 2011, Nanni et al., 2021.

European directive 98/2008/CE, of November 19th, define waste valorisation as any operation whose principal objective is that the waste can serve a useful purpose to replace other materials that, otherwise, would have been used to fulfil a particular function (European Parliament, 2008).

Valorisation is linked to circular economy concept. The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended. In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible thanks to recycling. These can be productively used again and again, thereby creating further value. This is a departure from the traditional, linear economic model, which is based on a take-make-consume-throw away pattern. This model relies on large quantities of cheap, easily accessible materials and energy [1]. Figure 2 shows a visual representation of circular economy model.

The benefits of using circular economy model are to protect the environment, reduce raw material dependence, create jobs and save consumers money.

Figure 2. Circular economy model. Source: [1].

During the process of winemaking, certain residues and by-products are generated. These by-products are regarded as highly polluting due to the presence of organic substances, pH, salinity, and heavy metal content, thus having negative repercussions on environmental and economic sustainability (Troilo et al., 2021).

2. OBJECTIVES

This work aims to accomplish two main objectives: the first objective is to gather information about winery solid wastes management and explore different treatments to valorise winery by-products. As a second, the knowledge gain in this field is going to be applied to effectively manage and valorise the solid wastes produced at Mas Sanmartí de Serrahïma, which is located in Pla del Bages. The final objective is to stablish a circular economy inside the winery by maximizing the reuse of all the wastes within the cellar.

To achieve this final goal, the following specific objectives have been identified:

- Through bibliography research, identify the different by-products generated from winery industry and the available techniques for valorising them.
- Apply the findings from the literature review to propose a sustainable treatment process to obtain by-products for a specific cellar named Mas Sanmartí de Serrahïma.
- Finally, design the selected treatment process and estimate the associated investment costs.

3. WINERY BY-PRODUCTS, VALORISATION AND EXTRACTION

This chapter describes the various by-products that can be obtained from winery waste. Additionally, it discusses the potential impact of these by-products on different sectors. Furthermore, it highlights the significance of bioactive compounds in human health. Moreover, it will explain the methods for obtaining these by-products, specifically focusing on biocomponent techniques for extraction.

3.1. WINERY BY-PRODUCTS

According to Figure 1, there are mainly three winery wastes: pruning wastes or wine shoots, wine lees and grape pomace, shown in green, orange and purple, respectively. Figure 3 shows a scheme with several options to obtain value-added products from vinification wastes.

Different industries can take advantage from these by-products, such as, agriculture, alimentary, cosmetics, bioenergy, pharmaceutical, medical, chemistry, textile, oenological, among others.

Grape stalks, about 7%, w/w of grape total weight (Troilo et al., 2023), are usually removed before the fermentation phase to avoid excessive wine astringency.

Grape pomace is the solid residue obtained after the pressing process and represents 20–25% (w/w) of the total weight of the freshly grape used for wine production (Balli et al., 2021; Troilo et al., 2021; Hayrapetyan et al., 2023). It is formed by grape skins, seeds, brunches and pulp.

Wine lees or vinasses are defined as the residue formed at the bottom of the container during the wine fermentation stage. It consists of a solid phase, looks like sludge, composed of yeasts and bacteria responsible for vinification. About 5 % w/w of total grape weigh are lees (Troilo et al., 2023).

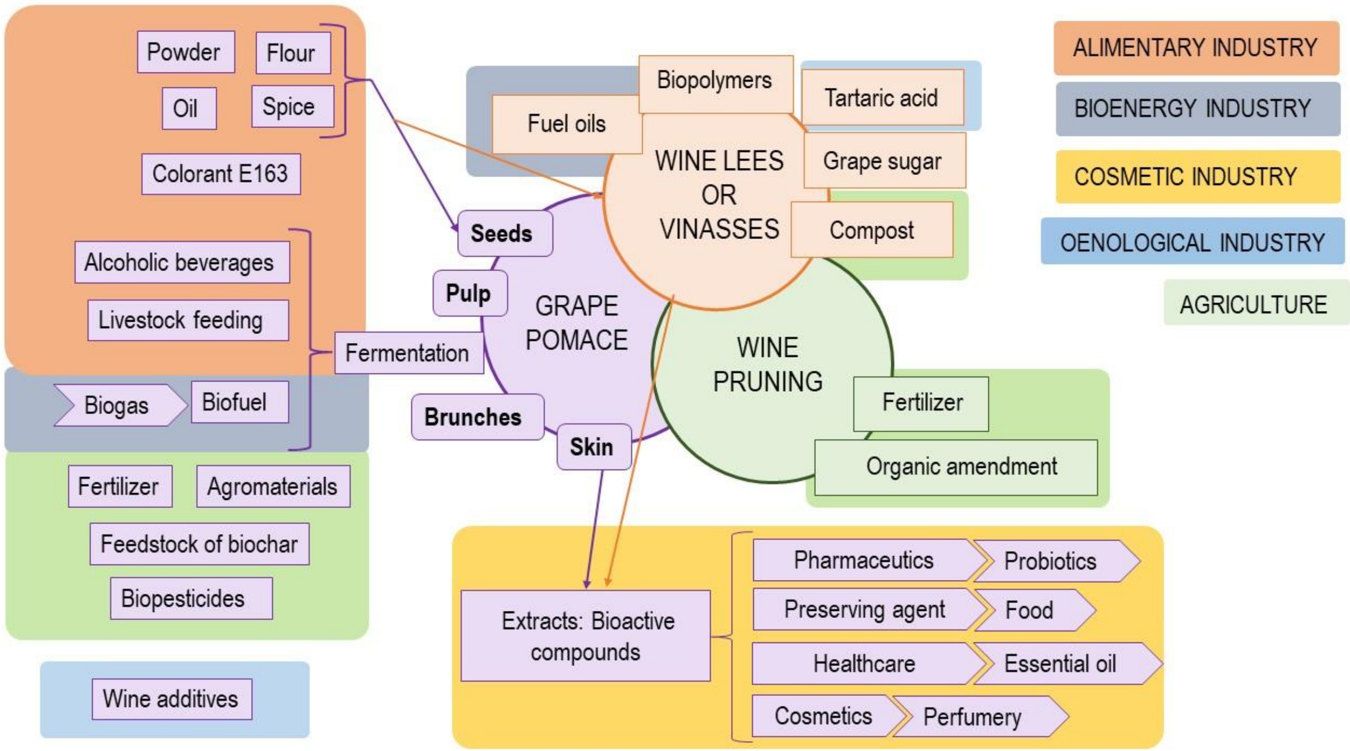

Figure 3. By-products obtained from different winery wastes. Source: own elaboration. Information extracted from Baronti et al., 2014; Putnik et al., 2016; Perdicaro et al., 2017; Deamici et al., 2018; Alarcón et al., 2020; Cozma et al., 2020; Frikha et al., 2021; Troilo et al., 2021; Bulos et al., 2023; Marchetti et al., 2023.

Nowadays, researchers are giving special attention to the extraction of bioactive compounds from winery by-products (Troilo et al., 2021). These bioactive compounds are mainly represented by polyphenols[1] and dietary fiber[2]. Grape pomace, wine lees and grape pruning are an important source of these compounds (Cozma et al., 2020). To highlight the significance quantity of biocomponents and their relevance in winery by-products, Figure 4 shows the main phenolic components present in these winery by-products.

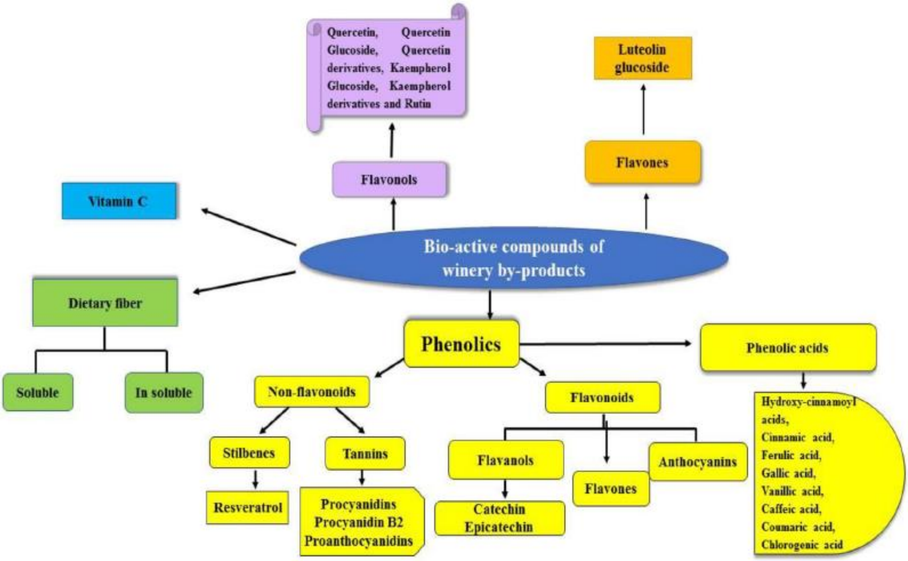

Figure 4. Bioactive components from winery by-products. Source: Chakka & Babu, 2022.

[1] Polyphenols. There are secondary metabolites produced by plants under stress conditions and have a significant function in the defence against pathogens, environmental stress and the attraction of pollinating insects. The variety of phenolic components depends on factors such as ultraviolet radiation, irrigated water, among others (Troilo et al., 2021; Bulos et al., 2023).

[2] Dietary fiber. It is defined as carbohydrate polymers with 10 or more monomeric units that are not hydrolysed by the endogenous enzymes in the small intestine of humans (Troilo et al., 2021).

The extraction of these compounds plays a crucial role inhuman health and food applications. For instance, they can inhibit the growth of food pathogens, be used in food packaging, or serve as an alternative of classic wine additives like sulfur dioxide (Deamici et al., 2018; Troilo et al., 2021). Figure 5 shows a diagram illustrating the significance contribution of polyphenols and dietary fiber to human well-being.

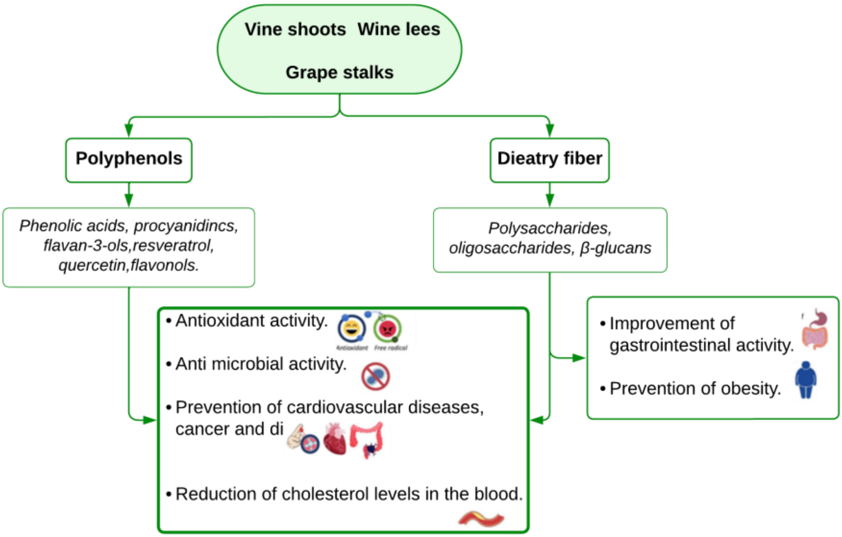

Figure 5. Polyphenols and dietary fibers affection in human health. Source: own elaboration, extracted from Troilo et al., 2021.

Definitely, if the aim is to obtain products of higher market value, there are possibilities for extracting organic acids, amino acids, alcohols, solvents, vitamins, and other secondary metabolites. All these products can have valuable applications in various industrial sectors, such as food, pharmaceuticals, medical and chemical industries, as well as textiles, leather processing, and plastic manufacturing. Appendix 1 provides a more detailed examination of other applications of winery by-products.

As an example, organic acids are precursors for the biosynthesis of polyhydroxyalkanoates (PHAs), which are fully biodegradable polymers with a broad portfolio of industrial applications, including packaging (Marchetti et al., 2023).

3.2. EXTRACTION TECHNOLOGIES TO OBTAIN WINERY BY-PRODUCTS

Grape pomace and wine lees are considered products with value and wineries can benefit from distillation to produce ethanol or tartaric acid (Novello et al., 2018; Pinto et al., 2023). However, the potential use of winery waste to produce these substances depends on the market value related to the management cost of the waste from the winery (Pinto et al., 2023). Alternatively, these waste materials can be utilized as a fertilizer, organic amendment or animal feed, all of which have shown positive results (Bulos et al., 2018).

Nevertheless, there is a particular interest in extracting biocomponents (Putnik et al., 2016; Troilo et al., 2021). One challenge in selective extraction is that polyphenols exhibit variations in their solubility and yield of recuperation (Castellanos-Gallo et al., 2022). There are both traditional and modern extraction technics available. The first one includes maceration, percolation, Soxhlet extraction, hydrodistillation and solid – liquid extraction, but they require a large volume of organic solvents and a long extraction time (Zhang et al., 2018; Castellanos-Gallo et al., 2022; Chakka & Babu, 2022). The second ones, modern technics, are characterized for being ‘green’ technologies with lower energy consumption, shorter extraction times, higher efficiency, and a higher purity of extracted molecules (Castellanos – Gallo et al., 2022). In Table 1 these advanced and sustainable technics for biocomponents extraction are briefly described, along with their advantages and disadvantages.

Table 1. Biocomponents extraction technologies. Source: own elaboration. Information extracted from Da Rocha & Noreña, 2020; Castellanos-Gallo et al., 2022; Chakka & Babu, 2022.

Technic	Description	Positive aspects	Negative aspects
Supercritical fluid extraction (SFC)	It consists in two steps: 1. Extraction of soluble substances from a solid matrix by supercritical fluid solvent (CO_2). 2. Separation of the compounds from the supercritical solvent, post-expansion. This technology involves the usage of transference of mass based on fluids, with the temperature and pressure above their critical values (Chakka and Babu, 2022).	Absence of solvent in the final product. Final product does not need post-treatment sterilization. It is used supercritical carbon dioxide. Has resulted in 86% recoveries of products from the grape pomace, making it economically convenient. It is usually used for grape seed oil.	General costs. Temperature and pressure above critical values. Absence of light and oxygen. Sample preparation. Use of modifiers (ethanol or methanol), it is optional.
Microwave-assisted extraction (MAE)	This process involves heating solid-solvent mixture with microwave energy and separating the desired compound from the solvent. Microwave heating is based on non-ionizing electromagnetic waves.	Green technology. Industrial applications. High quality of polyphenols.	Type of solvent. Solvent volume. Extraction time. Temperature. Microwave power.
Pressurized liquid extraction (PLE) or pressurized solvent extraction (PSE)	This technic involves applying pressure along with the use of temperatures above the boiling points of the solvents. Extraction processes using high temperatures helps increasing mass transfer and extraction rates.	Increment of polyphenols. Less time operating. Lower consumption of organic solvents.	High temperatures and pressures (800ºC and 6,8 MP).
Pulsed electric field (PEF)	In this technic the material located between two electrodes is exposed to a strong electrical field. The stress caused by the electrical field on the membrane leads to pore formation. The pore formation can be reversible or irreversible.	Nonthermal processing. Preservation method.	Electric field strength. Pulse duration. Industrial scale under develops.

Instant controlled pressure drop technology (DIC)	It consists of a high temperature/high-pressure short time treatment, exhibiting thermo-mechanical effects influenced by exposing to the raw material for a short time to saturated steam followed by an abrupt pressure drop towards the vacuum.	Green technic. Solvent: water vapour.	High temperatures and pressure. Mechanical stress.
Liquified gas technology (LGT)	Liquified gases are n-propane, n-butane and dimethyl ether. It can be isobaric or non-isobaric.	Low energy consumption. Under batch processing. Semi-continuous processing.	
Extrusion technology (ET)	The ingredients are injected under pressure in a barrel, they are stirred using one or two rigid screws, and they emerge at the other end through a grid, also known as a shaping dye. The primary operation process occurring in the barrel is mixing ingredients that are initially fed and added to the unit at different stages of the extrusion process. The secondary unit operation involves heating the mixture of ingredients. At the final stage of the extrusion, the ingredients are mixed steadily, where the mechanical action involved enables the processor to obtain specific textures such as crispy, soft inside, crunchy, texturizing, super expansion, etc.	Saves space. Saves energy. Highly adaptable. Extracts 68% of monomeric anthocyanins. Extracts 58% of flavanols.	
High pressure process (HPP)	Applies intense pressure at room temperature and over a short time. The combination of pressure and temperature can be selected to achieve the ideal conditions and best results. Works on Le Chatelier's principle and the Isostatic principle. Once the food product is loaded inside the vessel, it is filled with pressure transmitting fluid, i.e., water. Next, an intensifier is used to increase the pressure or to create forceful compressions. After compression, holding, and decompressions, the processed food product is removed from the vessel and packed conventionally.	Basic design components. Safe food without changing characteristics. Recovery of 70% of polyphenols. Recovery of 40% anthocyanins.	

In general, all these advanced sustainable techniques, may be subjected for future research to determine the limitations, including extraction cost, recovery time, stability, toxicity and percentage of purity (Chakka and Babbu, 2022).

On the other hand, other value-added treatments might be considered. Composting has gained interest due to the poverty of many soils in organic matter and susceptibility to erosion. Moreover, several studies indicated that soil amendment with compost from winery wastes increases soil organic matter content and microbial diversity, providing a slow release of nutrients (Pinto et al., 2023), reducing amount of sulphur and potassium added and improving soil quality and germination rate (Bulos et al., 2023).

Barring that, it is found that the presence of tannins and polyphenols in composting substrate may have a negative impact by inhibiting plant growth (Novello et al., 2018). Also, a low pH negatively affects the microbial activity (Pinto et al., 2023). However, these disadvantages can be overcome through proper composting design.

In conclusion, composting can serve as a suitable alternative technic for managing winery wastes and reintroducing it into the soil in accordance with the principles of a circular economy (Puyuelo et al.,2018; Pinto et al., 2023). Although compost may not the most value-added by-product, it is an affordable green technology that does not require excessive energy consumption.

3.3. COMPOSTING TREATMENT

Composting is a biological transformation from organic waste under controlled conditions (Pinto et al., 2023). It is a process for biodegrading organic material aerobically and in thermophilic conditions. Figure 6 shows a graphical scheme of composting process with its entries and exits. The final product, the compost, is a material rich in nutrients and in organic matter which can be used as a soil amendment. A theoretical reaction is shown in Equation 1.

organic material + O_2 + H_2O + microorganisms → compost + H_2O + CO_2 + NH_3 + Q [Eq.1]

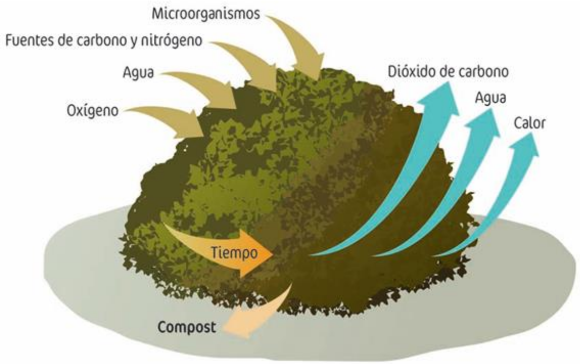

Figure 6. Graphical scheme of composting process with entries and exits. Source: Agència de Residus de Catalunya (ARC), 2016.

The goals of composting are:

- Facilitate the reintroduction of organic matter and phytonutrients into natural cycles.
- Obtain organic fertilizer which allows maintaining the fertility of the soil, quality production and preservation of environment.
- Reduce the volume, humidity and weight of the garbage.
- Produce alternative materials of substrates no renewables such as peat.

Perhaps the compost is not the most value-added by-product, composting is a green technology with low capital costs and easy to implement and operate.

The main variables which conditions composting are:

- Equilibrium between humidity and water. A spongy mixture of waste that allows correct water retention and sufficient porosity to facilitate air circulation.
- Nutrient balance. A good relationship between carbon and nitrogen is required ($C_{availabe}$/N).
- Microorganisms.
- Optimal pH.
- Temperature.

Figure 7 shows the optimal composting operational conditions.

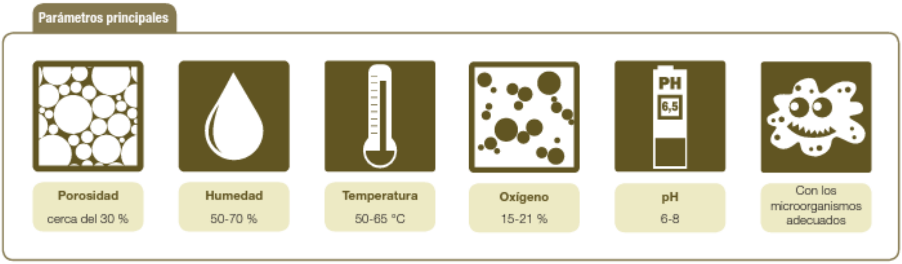

Figure 7. Optimal conditions for composting. Soruce: Agència de Residus de Catalunya (ARC), 2016.

Composting systems are developed mainly in two phases. Figure 8 shows a diagram of composting process with entries and exits.

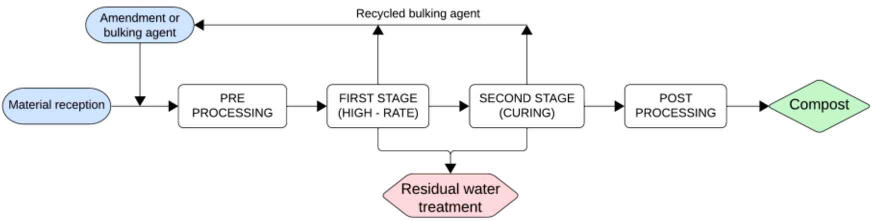

Figure 8. Diagram of composting process. Source: own elaboration. Information adapted from Agència de Residus de Catalunya (ARC), 2016; [2].

The first stage is where complex molecules break down into simpler molecules. It is a critical phase characterized by high oxygen uptake rates, thermophilic temperatures, high biodegradable volatile solids (BVS) reductions, higher odour potential and release of high energy [2]. The second stage, as is name says, is the curing and stabilization phase. It is where new macromolecules are constructed. Low temperatures, reduced oxygen uptake rates and lower odour potential is what is characteristic in this phase. Finally, a pre- or post- processing phases can improve the quality of compost. A preprocessing stage enables to start the process with a clean feedstock which gives an assurance of producing a high-quality product [2]. Moreover, a postprocessing stage gives the chance to enhance the desired product. For example, the particle size, texture, moisture content, colour, odour and general appearance can be modified.

There is a special attention on the temperature and microorganisms' evolution due to the temperatures reached during composting are determined by microbial activity. The heat generated during the composting process is due to the release of surplus energy during the microbial decomposition of organic matter. Although composting temperatures vary to some degree, they usually follow a similar pattern.

1. The initial phase in which temperatures rise (initial mesophilic phase).
2. The primary hot or thermophilic phase (> 45 °C).
3. The curing and maturation phase during which the temperature slowly falls again.

Figure 9 shows the temperature evolution with the three stages.

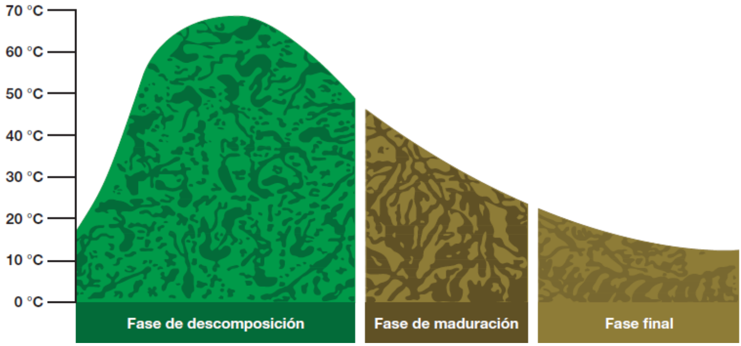

Figure 9. Temperature and microorganisms' evolution during the different phases of composting. Source: Agència de Residus de Catalunya (ARC), 2016.

As previously explained, the initial stage involves the generation of energy at a high temperature. This is the environment where a wide range of microorganisms that consumed organic matter can be found. Moreover, during the thermophilic phase, pasteurization takes place which is the procedure for killing pathogens and weeds. Moving on to the second phase, known as curing, energy is consumed and temperatures gradually decrease.

There are several approaches to categorizing composting systems. The most fundamental distinction is between systems that use a closed reactor to contain the composting material and those that do not, open systems. There are also systems that fall in between, known as and mid-open systems (Mendoza, 2012; [3]). Figure 10 shows a diagram illustrating the three categorized composting systems.

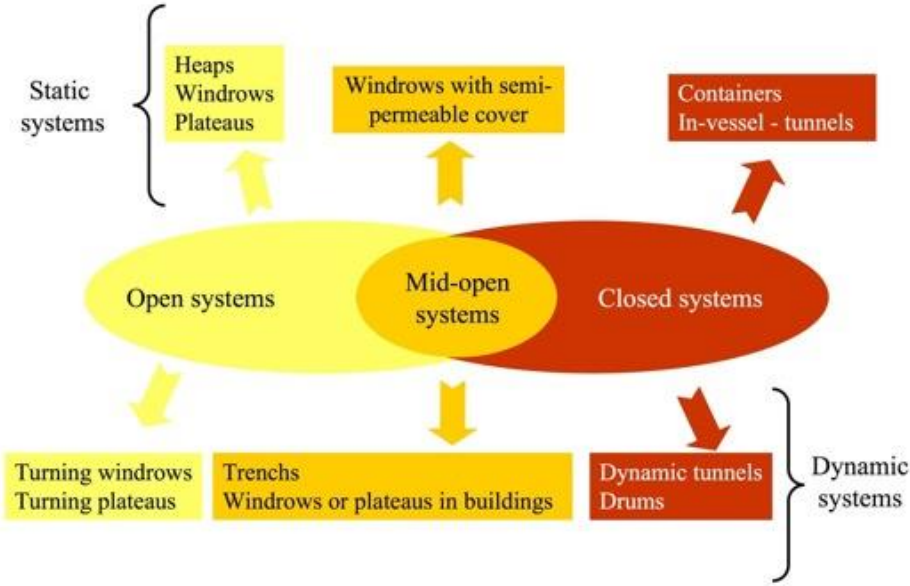

Figure 10. Main classification of composting systems. Source: [3].

Open systems, where the composting process occurs in open air, can be classified based on whether they maintain an agitated solids bed or employ a static bed, depending on the desired method of oxygenation. On the other hand, closed systems utilize a reactor for the process. Closed systems offer the advantage of being able to thoroughly control all aspects of the composting process, allowing for accelerated decomposition and requiring less space to work compared to open systems. However, they require significant capital investment and costs (Mendoza, 2012). Therefore, close systems will not be further discussed. Table 2 shows a summary of different open and mid-open systems, along with their advantages and disadvantages. Additionally, combining both systems to create mid-open systems could potentially offer a better composing technology, as it harness the advantages of both approaches [3].

Table 2. Open and mid-open composting systems with a description and advantages and disadvantages. Source: own elaboration. Information extracted from Román et al., 2013.

Entry	Technology	Description	Positive aspects	Negative aspects
1	Beltsville method	System in which a static windrow is periodically ventilated by an aspiration system of air from the ground. Air is supplied to the composting materials through perforated pipes embedded in each windrow, thereby eliminating the need for turning. The pipe ends are open. Air flows into the pipes and through the windrow because of the chimney effect created as the hot gases rise upward out of the windrow.	Simple to operate. Good results for wet substrates.	Not exert any temperature controll. Inhibition of microorganisms. Necessity of a bulking agent.
2	Rudgers system	Improves Beltsville method. It main differences are focused on the control system of the mass temperature that it does not allow increasing temperatures higher than 60ºC. There is a fan acting in overpressure or blowing, first thanks to the use of the timer and when the temperature of the material is higher than 60ºC, thanks to fan self-connexion according to the demand.	Improves beltsville method.	More expensive. Need straw or wood chips to create the windrow.
3	Windrow composting	Consists of placing the mixture of raw materials in long narrow piles called windrows that are agitated or turned on a regular basis. The turning operation mixes the composting materials and enhances passive aeration. Height, width and shape of the windrows depend on the nature of the feed material.	It generates temperatures high enough to compost grease and animal products. Easy to implement and operate. Low capital investment. Low capital costs.	Weather conditions influence the best shape of the piles. Windrow composting generates leachate, which can contaminate ground and surface water. Windrows can stink without careful odor control. Requieres a lot of land. Turning equipment requiered.

4	Gore cover	It consists in a physical barrier that is secured over compost heaps. As the waste decomposes, a thin film of condensation develops on the inside of the cover. Odors and other gaseous substances dissolve in this film and fall back into the pile, where bacteria continue to decompose them.	Contains odours and humidity. Accelerates the composting process. Retains heat.	High capital investment.
5	Bay composting In trench	Involves feeding materials into some kind of barrel, drum, or concrete-lined trench.	It can accommodate wide ranges of sizes. The largest trenchs uses less land than windrows. It poduces little odor or leachate. The weather does not affect.	It can take longer for the compost to cool off than it takes to make it. It is expensive. Requieres technical expertice than other methods. Expensive equipment need for turning.
6	Vermicomposting	Red worms in bins feed on food scraps, yard trimmings, and other organic matter to create compost. The worms break down this material into high quality compost called castings. Worm bins are easy to construct and are also available for purchase. One pound of mature worms (approximately 800-1,000 worms) can eat up to half a pound of organic material per day	Obtain two products: casting and worm tea. Usable for small quantities. Suitable for composting indoors.	Three or four months to produce usable casting. Worms are sensitive to climate change.

4. STUDY CASE

4.1. MAS SANMARTÍ DE SERRAHÏMA

Mas Sanmartí de Serrahïma is a family-owned winery dedicated to vineyard cultivation and wine production since 996. The property consists of seven hectares of land that is entirely dedicated to organic winery production.

The vineyard is certificated by Consell Català de Producció Agrària Ecològica (CCPAE), ensuring the establishment of a balanced ecosystem that respects the native flora and fauna of the territory.

The wine is crafted using native grape varieties that have been carefully selected from those that originally existed on the property at the late 19th century. The autochthonous varieties that are cultivated are Garnatxa, Sumoll, Mandó, Macabeu and Picapoll.

The vinification process follows the principal of minimal intervention, seeking the respect for the identity of grape varieties and territory.

To further enhance the quality of wine, the cellar is located underground allowing to work using gravity. This setup also ensures excellent temperature stabilization [4].

4.2. ESTIMATION OF WASTE GENERATION

The cellar Mas Sanmartí de Serrahïma has a vinyeard that spans 7 ha. Unfortunately, the Sanmartí cellar has not provided any information regarding the quantity of winery waste. However, it can be estimated the amount of easte by taking into account the total surface area of the vineyard and the spacing between grape wines. Considering that all grape wines are situated at 1.2 x 2.4 m between them, then the winery is likely to have a total of 24,306 grape wines.

After handling research in different bibliographies, it can be found that a mature grape wine can produce between 2 to 5 kilograms of grapes [5], [6], [7],[8],[9] and [10]. Considering an average number, the 7-hectare vineyard would yield approximately 62,530 kg of grapes. Based on this grape weight, an estimation can be made regarding the amount waste generated from pruning, grape pomace and wine lees. *'La web independiente de maquinaria agricola'* says that one grape wine can produce 1 to 1.5 kg of pruning [11]. For this study it is considered an average value of 1.25 kg pruning/grape wine. Besides, grape pomace is formed from brunches, pulps, skins and seeds with an approximate portion of 0.01, 0.33, 0.38 and 0.28 (w/w) respectively (Balli et al., 2021; Troilo et al., 2021; Bulos et al., 2023). Lastly, for wine lees it has found that represents de 7% of weight/weight of grapes (Balli et al., 2021; Troilo et al., 2021). According to all these data, Table 3 demonstrates the estimated generation of winery waste values. It is important to note that these estimations are obtained in a specific time period, as highlighted Table 3 as well.

Table 3. Estimation of waste generation. Source: own elaboration.

Entry	Input materials	Month	Quantity	Unit
A	Virtuous pruning waste (1st pruning)	February	15,000	kg
B	'Desgrollat' wastes	March	385	kg
C	Pruning waste	July	7,000	kg
D	Pruning waste (2nd pruning before vintage)	August	7,600	kg
E	'Rapa'. Pruning and grape waste	September	397	kg
F	'Brisa'. Grape pomace	September and October	10,319	kg
F.1.	Brunches		103	kg
F.2.	Pulps		3,205	kg
F.3.	Skins		3,921	kg
F.4.	Seeds		2,889	kg
G	'Mares'. Wine lees	September and October	671	kg

There are three main types of waste generated during the vinification process. According to Figure 1, the first waste generated is pruning stalks (marked in green in Figure 1 and in Table 3, entries A to E). The total amount of pruning is 30,382 kg which will be generated over a period of five months. Table 3 classifies the diverse types of pruning, entries A to E. Furthermore, it is important to note that the main waste generated before the vintage is low-degradable.

Once the vintage begins, the vinification process takes place, resulting in the generation of approximately 11 tonnes of waste. The first waste produced is grape pomace, shown in Figure 1 with a purple colour and identified as letter F. Grape pomace is a by-product of pressing whole grape bunches during the production of must (Hogervorst et al., 2017). It is the most abundant waste, accounting for 20% (w/w) of the total grape weight (Balli et al., 2021; Troilo et al., 2021).

Once the must is fermented, the second type of waste is generated. These are wine lees, shown in Figure 1 with an orange colour and identified as letter G. Wine lees are the residue that forms at the bottom of the container during the wine fermentation stage. It consists of a solid phase composed of yeasts and bacteria responsible for vinification. The lees account approximately 7 % (w/w) of total grape weight (Troilo et al., 2021). Therefore, it is estimated that there will be 671 kg of wine lees.

4.3. SELECTION OF THE VALORISATION METHOD

Considering the different types of valorising winery wastes and by-products, the selected valorisation method for the residues generated at the Cellar Mas Sanmartí de Serrahïma is the composting method. This method is considered the most economical compared to various extraction techniques. It also requires low capital investment and low operational costs. Moreover, composting aligns with the principles of a circular economy, making it a suitable technic for reintroducing winery wastes into the soil (Puyuelo et al.,2018; Pinto et al., 2023). Although compost may not be the most value-added by-product, it is an economical and sustainable green technology that consumes minimal energy.

The most important things to consider when choosing a compost system are (Gov/Compost Project, n.d.):

- The amount of organic material.
- The amount of space available.
- The amount of time to contribute in the maintaining of the system.

The first step is to choose where is going to do the composting: in piles or in bins. Using a bin to compost has its benefits, such as neatly containing organic waste to help keep the compost site orderly, minimizing the risk of pests (Gov/Compost Project, n.d.) and decreasing the troubleshooting of odours. However, composting large quantities of waste requires big bins which demands considerable space and a considerable investment in bin construction. In contrast, composting in open piles maximizes space efficiency and is less expensive than using bins. Therefore, composting in piles is chosen due to the need to compost large quantity of waste within a specific timeframe, while also desiring a lower capital investment. As a result, vermicomposting and bay composting, entry 5 and 6 in Table 3, are discarded.

The second step involves defining the aerated system. It is natural for air to flow through the windrow. However, even if the compost pile is carefully constructed, there may develop anaerobic pockets as the decomposer organisms consume oxygen throughout the composting process (Gov/Compost Project, n.d.). In addition to this, the weight of the organic matter can lead to compaction over time at the centre of the pile. To minimize compaction and oxygen depletion, the compost can be aerated using a turning machine (as mentioned in entry 3 of Table 2) or a forced aeration system (as mentioned in entry 1, 2 and 4 of Table 2). These methods are known as static systems or dynamics systems, according to Figure 10.

A study published by Pinto et al., 2023, focusses on the minimal intervention in composting grape pomace and recommends the use of a forced aeration system. The study compared various parameters such as temperature, moisture, pH and electrical conductivity, organic matter decomposition, nitrogen transformations and compost quality between static piles and turned piles. Based on these factors, static piles yielded better results compared to turned piles. The study also discovered that turned piles increase evaporative water in comparison to static piles. Additionally, forced aeration systems tend to dry out composting materials (European Union et al., 2022).

However, despite these findings, this study opts for turned piles, entry 3 of Table 2, because it is easy to implement and operate. The turning operation ensures a well-mixed composting material and passive aeration. Consequently, options 1 and 2 from Table 2 are deselected.

The main disadvantage of turned piles is that evaporation can increase, leading to a decrease of moisture levels (Pinto et al., 2023). As a result, there is a high need of rewetting. This is an essential factor because if the compost needs to be rewetted, the process complexity increases due to the availability of water resources causing a capital cost increment. Nonetheless, there is a way to avoid the need of rewetting turned piles. A study by Morales-

Vera et al., 2023 evaluated traditional turning composting in combination with a permeable cover technology. The use of a permeable cover reduced the water requirement by 17%. Consequently, this study is going to combine both technologies: turned piles with a permeable cover, specifically entry 3 and 4 from Table 2.

An alternative option of a permeable cover is the construction of a covert. However, constructing a roof to cover all the composting emplacement is not economically feasible due to the big dimensions. Moreover, it would have a negative visual impact because the composting plant will be placed within the same vineyard. Additionally, there will not always be composting, so with a movable cover, it can be removed and saved when is not in use.

Besides, it has been decided to construct a small covert specifically for the final phase of composting, known as curing, and to protect the final product from rain and ensure a high-quality end product.

To sum up, after carefully evaluating diverse alternatives, it has been decided to implement a mid-open system with turned windrows protected with a permeable cover and with a leachate recovery system. The leachate recovery system is necessary for all the composting methodologies to guarantee that composting is not a harmful activity to the environment. Additionally, a small covert will be constructed for the process of curing and storage the final product.

4.4. CHARACTERISATION OF THE RESIDUE

Before beginning the composting process for these three major vinification wastes (grape stalks, grape pomace and wine lees), it is important to know the characteristics of these residues and how they will impact on the composting process.

Grape pruning is a low-degradable organic waste. It is a source of phenolic compounds including tannins, flavan-3-ols, hydroxycinnamic acids, monomeric and oligomeric flavonols, stilbenes, as well as lignocellulosic compounds such as hemicellulose, cellulose, and lignin (Troilo et al., 2021).

Grape pomace, which represents the largest quantity of waste generated from the vinification process, is a moist sludge rich in phytochemicals. Table 4 shows the most important physical and chemical parameters related to it.

Table 4. Physical and chemical parameters for grape pomace characterisation as a composting feedstock. Source: own elaboration. Information extracted from Westover, 2006; Carmona et al., 2012; Burg et al., 2014; Pinto et al., 2023 .

Parameter	Value
Humidity	50 – 70 %
N – P – K – Ca quantity	2.0 – 0.5 – 2.0 – 2.0
pH	3.5 – 3.8
Carbon: Nitrogen ratio	17 – 30: 1
Electrical conductivity	Low
Organic matter	High content
Structure	Granular
Polyphenols	3.8 – 34.9 g/kg
Residual sugars	15 %
Ash	2.5 – 4.5 %
Cellulose	27 – 37 %
Proteins	6 -15 %

In accordance with Figure 7 (optimal conditions for composting), low pH is a problem because is to acid for microorganisms and compost microbes prefer a pH of 6.2 to become active (Burg et al., 2014). Also, form the viewpoint as a soil amendment, the presence of phytotoxic compounds such as ethanol and polyphenols may inhibit root growth (Pinto et al., 2023). However, it is rich in organic matter content and in potassium. C: N ratio is appropriate for the correct composting development (Brug et al., 2014). Perhaps moisture content is in optimal moisture range, if it increases wet piles may continue to ferment producing acetic acid (Westover, 2006).

Wine lees, which are the solid phase obtained at the bottom of the fermentation container, are a wet sludge that is rich in ethanol, tartaric acid, phenolic compounds and yeast cells (Bulos et al., 2023). Table 5 shows chemical parameters of wine lees.

Table 5. Wine lees parameters characterisation as a composting feedstock. Source: Bulos et al., 2023.

Parameter	Value
Ash	10.96 g/100g
Proteins	16.53 g/100g
Lipids	7.16 g/100g
Sugars	4.13 g/100g
Total dietary fibre	51.91 g/100g

4.5. COMPOSTING DESIGN

Through this section, it will be explored the different stages involved in the design of a composting plant. The process begins with a preprocessing phase, where the composting feedstock is prepared and conditioned. Next, the windrows composting dimensions will be determined and presented in detailed plans with the inclusion of emplacement, leached deposit design and materials. Lastly, the curing stage will be discussed, which is crucial for obtaining the final product and ensuring its proper storage.

4.5.1. Preprocessing: compost conditioning

Grape pomace and wine lees are wastes characterised for being a wet sludge substrate to the compost process. The need of bulking agents must be essential for the correct development of composting [2]. A bulking agent is a material, organic or inorganic, of sufficient size to provide structural support and maintain air spaces within the composting matrix. Wood chips are the most common bulking agent although the use of other materials, such as pelleted refuse, peanut shells and tree trimmings, had been reported [2]. In this design, pruning matter from vinification process will be used as a bulking agent. It is an ideal choice because it is a low-degradable waste and will provide the necessary structural support for the windrow. All pruning, from entry A to E form Table 3, is generated between January and August-September, just before the vintage begins. These approximately 30 tonnes of waste will be triturated using a shredder with a particle size of 10 cm, at the same time as the residue is generated (Román et al., 2013). This size is considered because larges particles can create aeration channels, which lowers the temperature and slows down the process. On the other hand, if the particle size is smaller than 5 cm, the particles become too fine and create small pores that fill with water, facilitating compaction of the material and restricted air flow, resulting in anaerobiosis (Román et al., 2013). Therefore, from February to August-September, nearly 6 months, the composting plant will focus on sizing the grape stalks, which will be useful for the preprocessing of grape pomace and wine lees. Appendix 2.1 shows the technical sheet with further details.

Therefore, homogenization is necessary to achieve the desired porosity and moisture levels. The mixture of organic and structural material must be done with careful consideration of the minimum volumetric portion to ensure a proper homogenization. When there is a lack of porosity, the volumetric portion of structural/organic material (Ve/Vr) should be higher than 2/1, with a recommended portion of 4/1 (Agència de Residus de Catalunya (ARC), 2016).

However, there have been studies by Westover, 2006 and Carmona et al., 2012, which successfully composted grape pomace and grape stalks in a 1:1 ratio (v:v). For this study, it has opted for a volumetric portion of 1:1, because these previous studies specifically composted grape marc. By using this ratio, 19 tonnes of grape stalks are left over, which can be used as a soil conditioner to improve soil fertility and water retention.

Consequently, the total quantity of waste to be composted is 22 tonnes, consisting of 11 tonnes of grape pomace and wine lees and 11 tonnes of grape stalks.

4.5.2. Windrows design

The dimensions of the piles will be determined following the recommendations outlined in Figure 11 and 12. Numerous studies in the literature agree on the design of piles with a height of 1.5 – 2 m and a width of 1.5 – 4 m (Carmona et al., 2012; Román et al., 2013; Michel et al., 2021). Moreover, when estimating the dimensions of the compost pile, it is important to consider that during the composting process, the pile will decrease in size (up to 50% by volume) due to compaction and the partial loss of carbon in the form of CO_2 (Román et al., 2013). Also, it is worth noting that Figure 12 shows the dimensions of a forced aeration static pile (ASP). Despite the fact that this study has opted for a turned pile, the recommended dimensions of the piles are still applicable to this work.

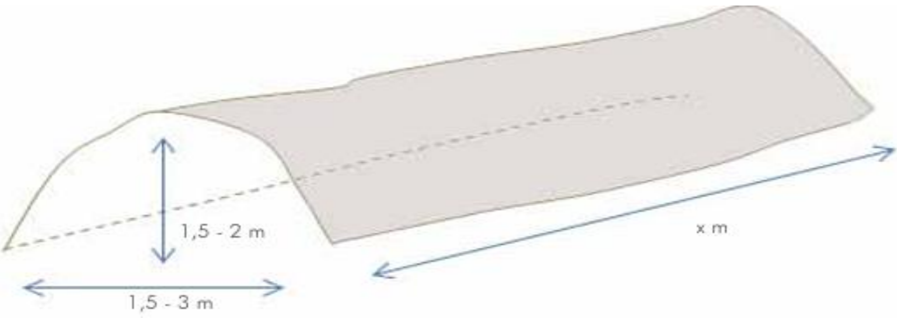

Figure 11.Standards of composting pile's dimension. Source: Román et al., 2013.

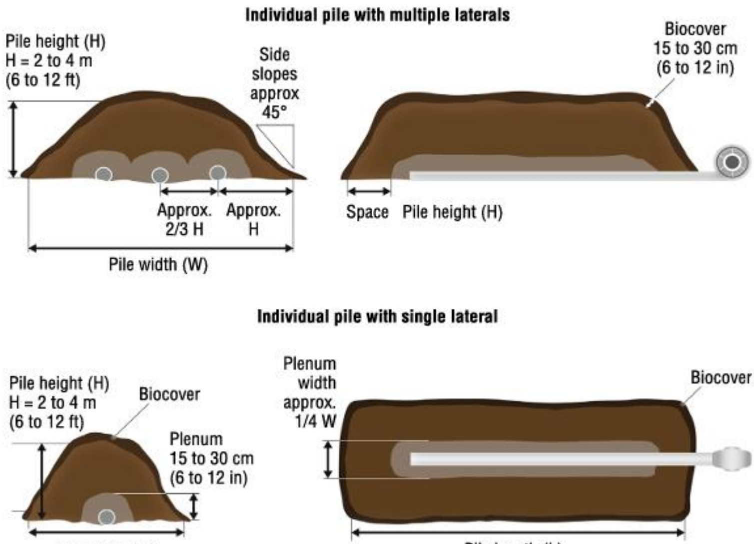

Figure 12. Layout and example dimensions of a Basic ASP with individual piles. Source: Michel et al., 2021.

It will be considered a triangular or trapezoidal shape with 45º of side slopes. Typically, the width of an individual pile is determined by the volume of feedstock to be composted in each batch, once the height and the length of the pile have been determined. Equation 2 shows the formula for calculating the width of pile.

$$w = \frac{V}{L \cdot h} + h \qquad \text{[Eq. 2]}$$

w is the pile width.	L is the pile length.
h is the pile height.	V is the required volume of the pile.

However, not always the length and the height would be determined. An alternative approach is to settle on a pile width and height lateral and then calculate the pile length required to achieve the desired volume. In this case, Equation 2 can be rearranged to calculate the pile's length as Equation 3 shows.

$$L = \frac{V}{h \cdot (w - h)} \qquad \text{[Eq.3]}$$

In order to determine the dimensions of windrows containing 22 tonnes of organic matter, it is necessary to kwon the volume of the pile. Grape pomace, wine lees and grape stalks have their own bulk density. Many reviews in literature reported a range of bulk densities. For the purpose of this study, a medium density will be considered. Table 6 shows the density range, medium density and the sources of this information.

Table 6. Bulk density range, medium density, and the source. Source: own elaboration.

Organic matter	Density range [kg/m^3]	Medium density [kg/m^3]	Source
Grape pomace	450 – 600	525	Burg et al., 2014
Wine lees	1.1 – 1.4	1.25	Fia et al., 2016
Grape stalks	200 – 340	250	Pangavhane & Shrikant, 2012

All of these organic materials require homogenization to produce high-quality compost. Homogenization will be achieved through layering (Mendoza, 2012). Thereby, the total density of the composting pile will be 37.18 kg/m^3. The homogenization process will be facilitated by using a turning composting machine. Consequently, ensuring proper distribution of the layers is crucial.

Table 7 shows the dimensions of piles. The length is a restricted variable because it has been chosen to be the maximum length achievable, as shown in Figure 13. A length of 25 m has been opted for, slightly longer than a tennis court. Additionally, the height has been set at 2 m, adhering to the standard height dimension. The width has been selected in accordance with the recommendations provided in Figure 13. Considering a triangular-trapezoid pile with 45º side slopes, the volume will be calculated by employing the height and the base area.

Table 7. Windrow design dimensions. Source: own elaboration.

Establish values		
Total quantity	22	t
Total density	37.18	kg/m^3
Total volume	600	m^3
Length	25	m
Height	2	m
Base width	4	m
Windrow volume	100	m^3
Number of windrows	6	Piles
Total width	38	m

Layers distribution will be done combining dry matter (pruning stalks) with wet sludge (grape pomace and wine lees) until the 2 m height is achieved. The first layer will be formed by the pruning stalks as well as the last layer. Each layer will have 40 cm of height. Consequently, to reach the 2 m of total height, it will be necessary to form 5 layers of 40 cm height. With this layer’s height and distribution, the first and the last layer are formed by grape stalks.

Table 7 shows that six composting piles, measuring 25 m x 4 m x 2 m (LxWxH) will be created. Each pile will compost 100 m^3 of organic matter. The space between composting rows will be 2 m, resulting in a total width of 38 m.

As mentioned earlier, the compost windrows will be covered with a semi-permeable membrane. There are various quality materials to cover the windrow. The most important fact is that the cover needs to be semi permeable. Looking at diverse brands of semi-permeable covers, the best well-known brand for this type of composting is Gore. However, the official website does not provide an approximate price [13]. Although, other brands must be found with their respective prices. AChinese supplier on Alibaba website offers two different covers [14] and [15]. Technical sheets for both covers are provided in Appendix 2.2. Although both covers are quite similar, they differ in some of the materials used. One major difference is the coating type, with the first cover using a high-density polyethylene (HDPE) and the second cover using polyurethane (PU). While borh HDPE and PU are types of plastics, they have different properties, types of products, and manufacturing processes. HDPE is a type of thermoplastic, while PU is a thermoset [16]. Unlike thermoplastics that can be melted and reform, thermosets offer better performance under high temperatures while remaining in their permanent form. Table 8 shows a chart to breakdown of the differences between polyurethane and polyethylene.

Table 8. Differences between HDPE and PU. Source: [16].

Polyethylene	Polyurethane
Solids and foams available	Can be custom formulated to meet exact design needs
Limited durometers can be achieved	Wide variety of durometers[a] to choose from
Low resistance to heat	Higher durability; Able to withstand various temperatures from -80°F up to 300°F
Difficult to bond	Can bond to various subcomponents during the molding process
Can be made conductive with the use of carbon black	Improved resistance to electric static buildup, without the use of carbon black.

[a] Durometer: a piece of equipment for measuring the hardness of a material, in particular plastic or rubber. Definition extracted from Collins dictionary.

One characteristic that determines what is best for this study is heat resistance. During composting, temperatures will reach high values and low resistance could cause significance problems for the process. Another factor to consider is the backing layer. The first cover is made from nylon, while the second cover is made from polyester. Perhaps nylon is more resistant than polyester, coating types has a major priority when selecting a material.

To sum up, opting for the PU cover type is a better choice because it provides much more resistance to high temperatures compared to HDPE. However, price would be higher.

Once the pile has been formed, the only management necessary is to turn or mix it with a suitable machine. Turning helps to homogenize the mixture and regulate its temperature, eliminating excess heat, controlling moisture, and increasing pile's porosity to improve ventilation. After each turning, the temperature drops to the order of 5 or 10ºC, rising again if the process is not yet completed. Turning should be done by preventing turning machines from passing over the pile and compacting it. There are machines which remove or move the compost, allowing proper aeration. Many of these machines are equipped with a splined or serrated rotor shaft, which allows them to remove material from the pile without disrupting its structure. There are different models with different designs adapted to diverse composting size's windrows. They can generally be classified as turners attached to a tractor or self-propelled turners. The best option depends on individual needs. In this case, a self-propelled turner is preferred because it can both turn the piles and homogenize them, while the other option would require a tractor specifically adapted with a turner. This would be more expensive than choosing a self-propelled machine. Therefore, it has been decided to purchase a self-propelled turner on Menart website [17]. The model which suits with the pile's dimension designed is SPM – 47. Appendix 2.3. shows the technical specifications.

4.5.3. Leachate deposit design

Composting process produces some leachate which need to be collected to avoid infiltrations and ground pollution.

In general, to calculate the capacity of a leachate tank, approximately a value of 5% (0,05 m^3/t) of the volume of waste in process can be considered (Agència de Residus de Catalunya (ARC),2016).

Consequently, if the volume of waste is 22 tonnes, the deposit capacity needs to be approximately 1.12 m^3. In order to collect and store the leached, the tank must be controlled and impermeable. Most deposits are made of hight-density polyethylene (HDPE) or polyester. However, polyethylene is better than polyester in several ways. Firstly, polyethylene has greater resistance and is stronger against potential cracks [18]. Additionally, polyethylene responds to the requirements set by health authorities for the transport of substances. Secondly, polyethylene is resistant to humidity, corrosion and acid and has a non-porous surface [18]. This is basic for an optimal storing deposit situated underground. Furthermore, HDPE presents a good resistance abrasion compared with other materials. Figure 13 shows several abrasion curves for various types of materials, according to the Darmstadt procedure.

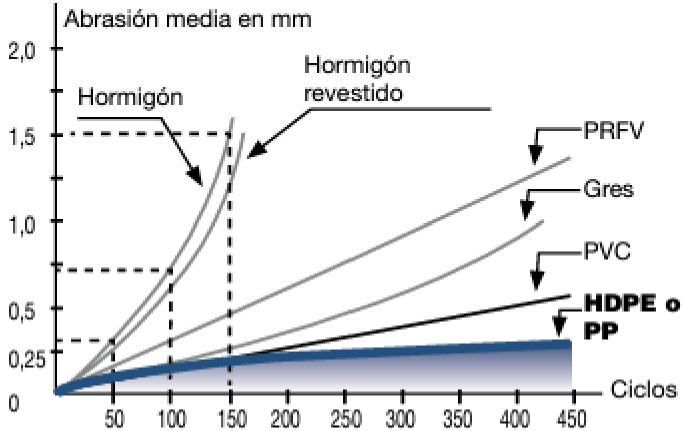

Figure 13. Abrasion curves for various types of materials according to the Darmstadt procedure. Source: Grupo PPA Tank. & Productos Plásticos Anticorrosivos., n.d.

'Hidraulicat' is going to be the supplier of the HDPE deposit. Deposit model is TH – 3000 with a 2,800 L capacity [19]. Although capacity calculated is 1,119 L, 1,438 L are going to be leftover for any unexpected situations. For instance, if it rains the water that has contact with the windrows is considered contaminated, dirty water, and needs to be treated as well as leached (Agència de Residus de Catalunya (ARC), 2016). Appendix 2.4. shows the tank specifications.

4.5.4. Emplacement and covert design

The 6 composting design piles will be placed on a waterproof concrete floor. Each windrow will have a 2% of slope, as recommended by Román et al., 2023 and European Union et al., 2022. Appendix 2.5. shows the waterproof concrete technical sheet.

Moreover, a covert will be installed to complete the curing phase and preserve the final compost. When the compost is finished, approximately 50% of the initial matter will be reduced. Therefore, the covert will need to save approximately 11 tonnes of compost. To accommodate this, three consecutive coverts bays will be constructed. The dimensions of this these coverts can be found in Table 9.

Table 9. Covert dimensions. Source: own elaboration.

Covert dimensions		
Final compost quantity	11	t
Final compost volume	300	m^3
Covert pile: supposing it is a parallelepiped		
Width	6	m
Length	6	m
Height	3.5	m
Number of bays	3	Bays
Total width	18	m
Total length	6	m
Total height	4	m

Each bay will have a volume of 100 m^3 of waste. The reason for constructing three bays is because not all the organic matter will be composted at the same time. Having three bays allows for better control of the final product. The walls of the bays will be constructed with bricks and the roof with corrugated steel panels. Appendix 2.6. shows the technical sheets.

The compost plant will require approximately 1,200 m^2 of space. Referring to Table 7, the total width of the six windrows will be 38 m, considering a space of 2 m between each pile. Also, the total length will be 27 m, accounting for a 1 m margin on both ends. Considering the covert's width and 1 m of margin, the overall dimensions of the plant will be 45 x 27 m. Figures 14, 15 and 16 show three different views the composting plant.

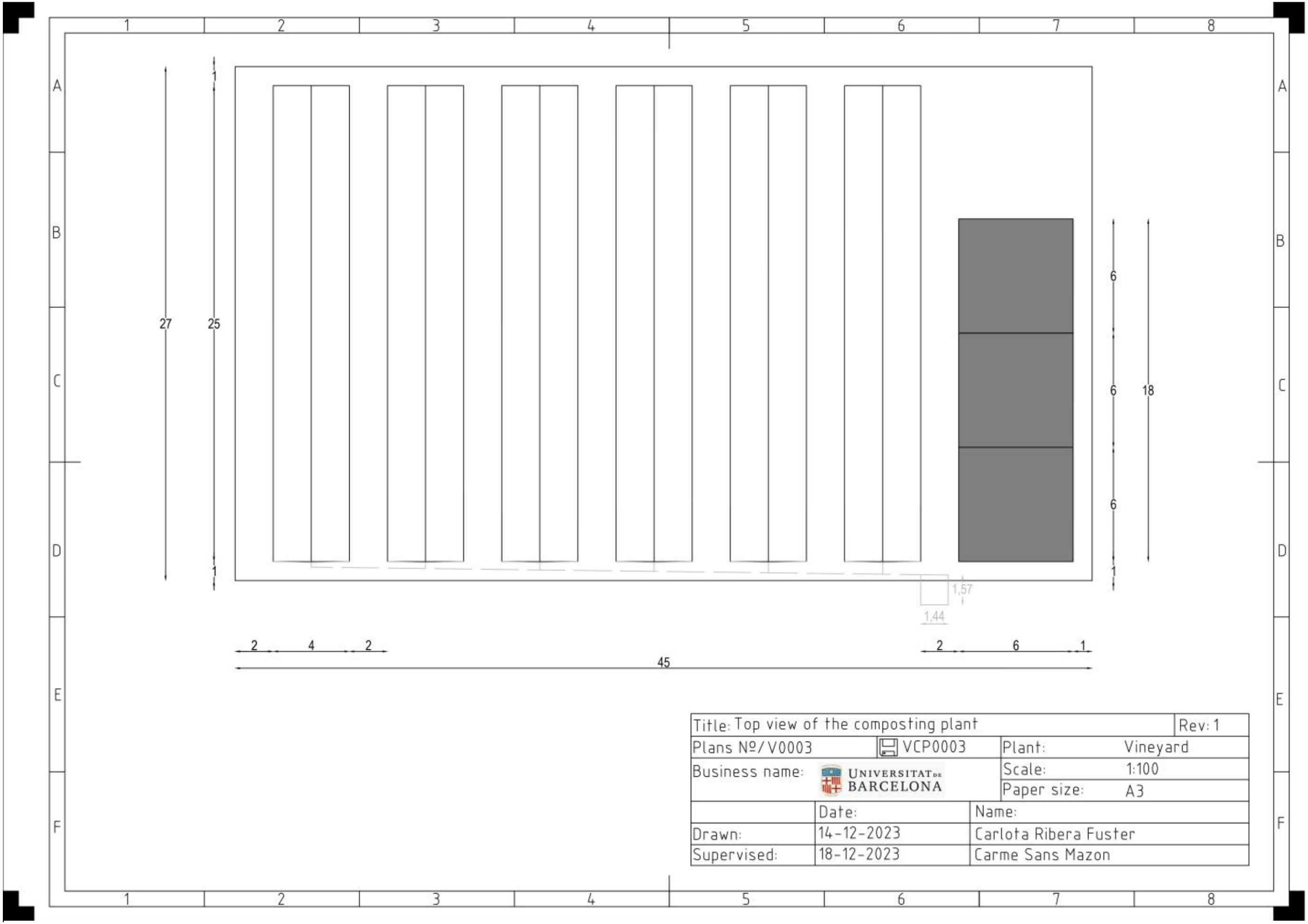

Figure 14. Top view of the composting plant. Source: own elaboration.

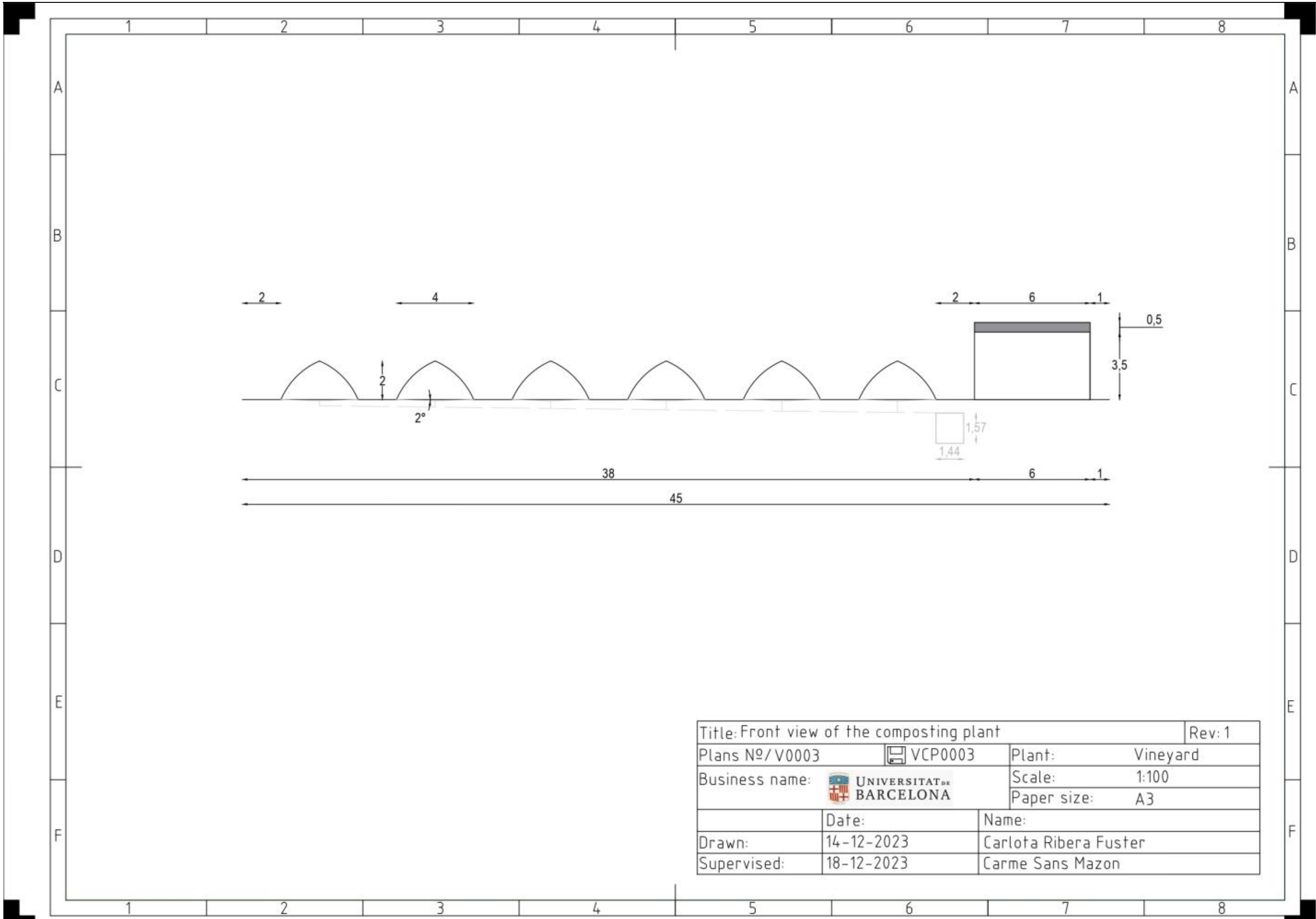

Figure 15. Front view of the composting plant. Source: own elaboration.

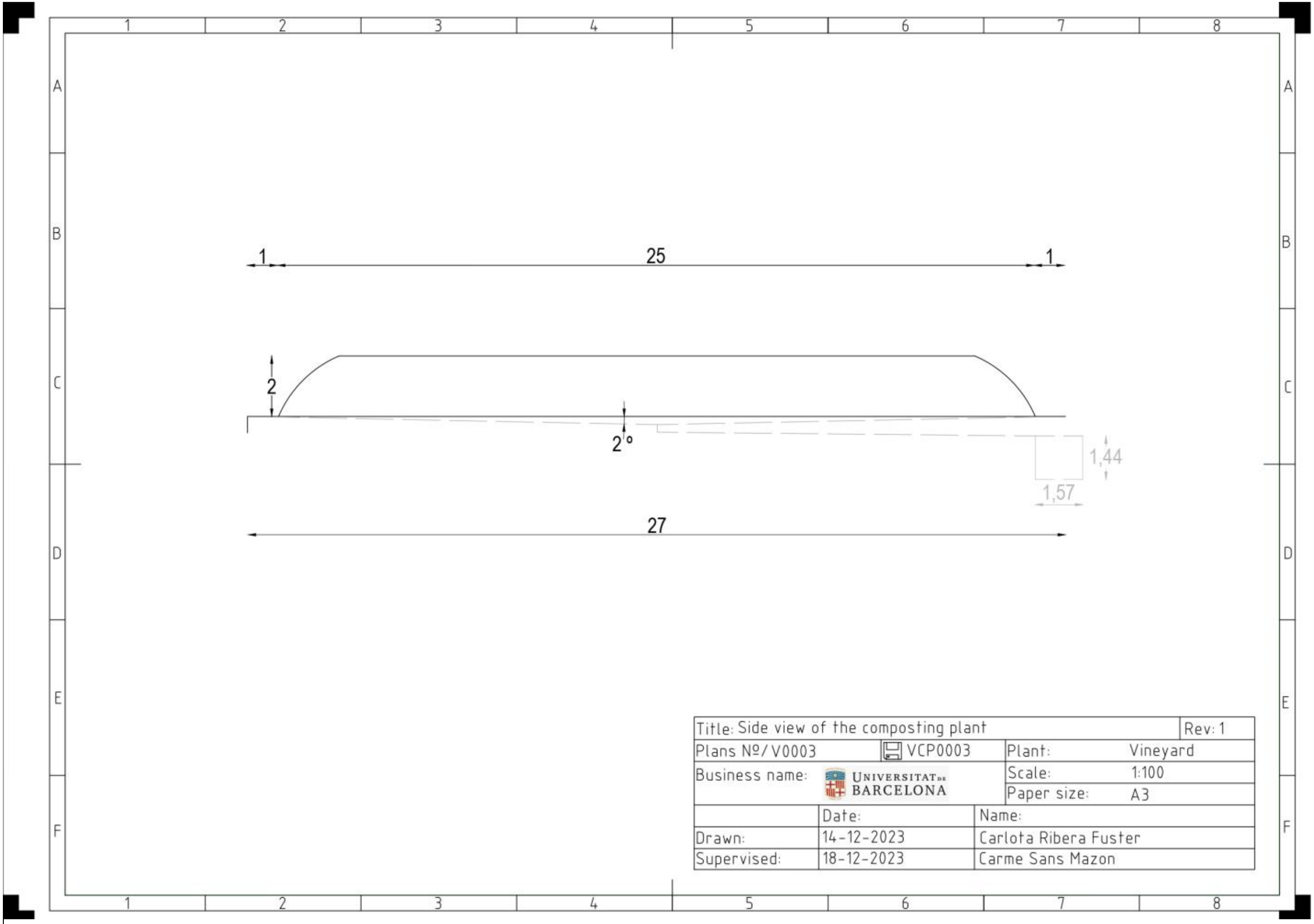

Figure 16. Side view of the composting plant. Source: own elaboration.

5. PROCESS OPERATION AND CONTROL

This section will discuss the development of various parameters during the composting of grape marc, wine lees and grape stalks. The information provided is derived from multiple experimental studies (Westover, 2006; Burg et al., 2014; PacWastePlus, 2022; Pinto et al., 2023). Although the best option is to obtain your own experimental results, conducting a comprehensive literature research can provide a general understanding of what to expect. The parameters to be evaluated include temperature, moisture, pH and odour.

Monitoring of the composting process is essential to maintaining optimal conditions and producing a high-quality product (PacWastePlus, 2022). Figure 17 shows the values to be achieved for a quality compost.

Characteristic	Unit	Optimum	Acceptable Range
Moisture content	**% (w/w)**	50 - 60	40 – 65
Carbon to nitrogen (C:N) ratio		25 – 40 : 1	20 – 60 : 1
pH		6.5 – 8.0	5.5 – 9.0
Particle size	Cm	< 5	Variable
Bulk density	**kg/m³**	400 - 600	< 700

Figure 17. Values for a quality compost. Source: PacWastePlus, 2022.

All the equipment required for the monitoring with the specification's factsheets are shown in appendix 2.7.

5.1. TEMPERATURE EVOLUTION AND CONTROL

Temperature is the key measured indicator for the state of the composting process (PacWastePlus, 2022). According to Figure 9, Table 10 shows temperature range values to achieve during the different composting phases. Monitoring temperature and understanding these temperatures will assist in the management of the composting process.

Table 10. Composting temperatures guidelines where highlights the general range of temperature during the composting process. Source: own elaboration adapted from PacWastePlus, 2022.

Transition from mesophilic to thermophilic microbes	40 – 45 ºC
Good range for thermophilic composting	55 – 65 ºC
Minimum temperature for pasteurisation	55 ºC
Level at which microbial populations decline and compost process slows	>70 ºC

Measured values reported in the literature (Westover,2006; Burg et al., 2014; Pinto et al.,2023) indicate that it takes up to three weeks for windrows' temperatures to reach the peak of thermophilic range of 55 – 65 ºC. These high temperatures need to be maintained for a period of seven weeks. This prolonged duration is necessary to effectively kill weed seeds and pathogens (Westover, 2006). Also, it plays a special role in ensuring the hygienic parameters of the compost (Burg et al., 2014). Moreover, a study by Westover 2007, recommends keeping pile's temperature below 70 ºC to reduce the risk of combustion and loos of beneficial organisms.

It is only after two months and a half that the temperature gradually declines from thermophilic range to the ambient temperature. This phase is crucial for the maturation and finalization of the composting process (Pinto et al., 2023).

Frequent temperature monitoring is essential during the first stages of composing when significant changes happen (PacWastePlus, 2022). Temperatures should be monitored throughout the composting process to (PacWastePlus, 2022):

- Provide information on the progress and stage of the composting process.
- Provide support for operational decisions (especially when and how often to turn or when to add water).
- Ensure that pathogens and weed propagules are absent from the end-product.

According to PacWastePlus 2022, proper temperature monitoring for the composting process should be based on its duration. If the composting process takes more than six weeks, temperature samples should be taken twice a week for the first four weeks and weekly thereafter. This recommendation aligns with the findings of Carmona et al., 2012 and Burg et al., 2014, who conducted studies that involved weekly temperature measurements.

Daily temperature measurements are not necessary for composting grape marc because takes a long time and pasteurisation occurs predominantly within the first 2 to 4 weeks of composting. The longer period of composting at elevated temperatures provides an additional safeguard against pathogens and weeds, reducing the need for frequent temperature monitoring (PacWastePlus, 2022).

Temperature monitoring should occur at a similar time of the day. The use of quick-response temperature probes reduces the time required to record measurements and increases accuracy of temperature readings (PacWastePlus, 2022). However, it is not recommended to measure the temperature immediately after the windrow is turned because the temperature drops significantly to approximately 5 or 10ºC.

It is crucial to monitor temperature in at least six different windrows points. Figure 18 illustrates the expected temperature fluctuations in a standard composting pile that exceeds 2 m^3 in size.

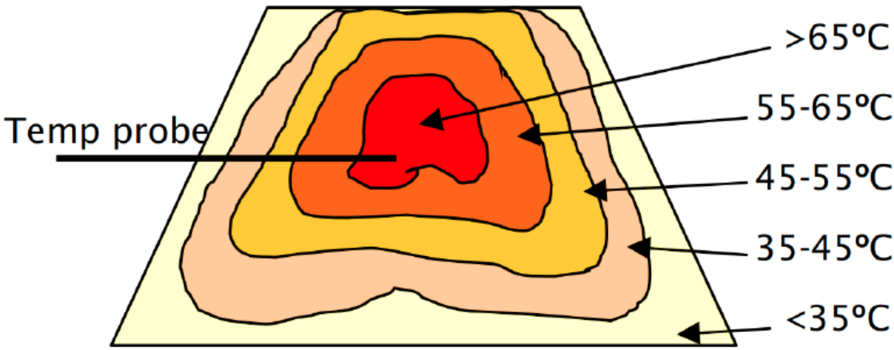

Figure 18.Schematic temperature variation within a typical composting pile. Source: PacWastePlus, 2022.

The six different depths for temperature monitoring would be (Carmona et al., 2012 and Burg et al., 2014):

1. In the centre of the windrow.
2. At half height in depth on the middle of width's pile.
3. At 20 cm in height depth.
4. At 60 cm in height depth.
5. At 100 cm in height depth.
6. At 140 cm in height depth.

To sum up, temperature monitoring is essential for determining the composting phase of organic matter. Consequently, it also determines the retention time.

5.2. MOISTURE CONTENT EVOLUTION AND CONTROL

Moisture is vital for the survival of all living organisms, including microorganisms found in compost piles. The optimum moisture level to begin the composting process typically ranges between 50% and 60%. Measured moisture values in compost piles show that pomace is a material with high moisture content (Burg et al., 2014). A larger proportion of grape pomace in the compost mixture has a positive effect on maintaining the required moisture. However, an excessive portion of grape pomace can contribute to the creation of anaerobic conditions and hinder the progress of the composting process (Burg et al., 2014).

During the latest stages of composting, it is common for the moisture content to fall below 40%, making it easier to handle, screen and store the compost. Nevertheless, it is recommended to take precautions to ensure that the compost does not dry out too much as microbial activity ceases below approximately 30% of moisture content.

There are different ways to monitor moisture content. The simplest approach is to visually inspect the pile and physically handle the material (PacWastePlus, 2022). However, although there are moisture meters available, their accuracy is questionable [20]. A more accurate way of determining moisture content is to weigh a sample of the composting material before and after it has been dried (PacWastePlus, 2022). Although the weighing and drying processes are straightforward, they required specific equipment and time for results to become available. To carry on the drying process, a laboratory drying oven can be utilized.

The basic procedure for determining moisture content by weight is as follows (PacWastePlus, 2022):

1. Weigh the container that will hold the material sample.
2. Weigh the ‘wet’ weight of the compost sample and deduct the weight of the container.
3. Dry the sample until no moisture is left.
4. Weigh the ‘dry’ weight of the sample and deduct the weight of the container.

5. Determine the weight of the water in the sample by deducting 'dry' weight from 'wet' weight.
6. Determine the moisture content, expressed as decimal fraction, by dividing the weight of the water by the wet weight of the sample.

Despite this procedure needs time, moisture content will be determined once a week. Therefore, compost samples need to be representative. For this reason, samples will be taken at two different depths and three equidistant points along the length:

1. Sample extracted at windrow centre.
2. Sample extracted at half width of windrow.

Moisture content of the composting process during pasteurisation should generally be between 50% and 60% (PacWastePlus, 2022). If it is outside this range, the following remediation measures are recommended:

- If moisture content is lower than 50% (too dry), add water to the pile (Burg et al., 2014).
- If moisture content is higher than 60% (too wet), add more bulking agents such as wood chips.

5.3. OXYGEN EVOLUTION AND CONTROL

Oxygen is essential for microbial activity and compost requires a minimum concentration of about 5% for aerobic microorganisms to function effectively (PacWastePlus, 2022). The presence of oxygen in compost piles is replenished through convection and diffusion (PacWastePlus, 2022). Convection refers to the movement of outside air into the compost heap as hot air rises through the pile and exits from the top, creating a concentration deficit. Diffusion then transports oxygen into the smaller pores of compost and into the water layer surrounding compost particles (PacWastePlus, 2022).

Nevertheless, oxygen levels are not always feasible due to the difficulty and cost associated with obtaining accurate data. In addition, proper compost development can be achieved by monitoring temperature and moisture levels (PacWastePlus, 2022).

5.4. pH EVOLUTION AND CONTROL

The pH value of the raw material is acidic and disadvantageous. During the first 6 weeks, the pH values were generally low, decreasing the risk of NH_3 volatilization during the thermophilic phase of composting (Pinto et al., 2014). However, the pH slightly increased during the subsequent six weeks, possibly due to the breakdown of organic acid compounds and organic nitrogen degradation, resulting in the formation of amines and ammonia and further nitrification (Carmona et al., 2012; Pinto et al., 2023).

The final pH value may depend on the nature and proportion of wastes present in the mixture (Carmona et al., 2012). However, many reviews in literature agree that the final compost of grape pomace and grape stalks generally has a pH between 7 and 8 (Carmona et al., 2012; Pinto et al., 2023).

It is recommended to assess the pH at the beginning of the composting process as their degradation results in the formation of organic acids, which can lower the pH to the point where microbial activity is inhibited (PacWastePlus, 2022). As the procees continue, the pH rincreases as organic acids are oxidised and ammonia is formed and volatilized. Typically, the pH settles between values of 7 and 8 during the maturation phase. Odours from ammonia production can become a problem when the pH exceeds 9. pH sampling will be accomplished with the same frequency as temperature mesurements. However, pH will be measured by extracting compost samples at two different depths in three different equidistant points along the length:

1. Sample extracted at windrow centre.
2. Sample extracted at half width of windrow.

pH suggested ranges from 5 to 7.5. If it differs it is necessary to follow this:

- If the pH is lower than 5 (acidic), it is necessary to improve air circulation and add drier feedstock with larger particle sizes such as shredded high fibrous woody material. Adding crushed coral sand or wood ash may also improve the alkalinity and aid in neutralising a compost pile (PacWastePlus, 2022).
- If the pH is higher than 7.5 (alkaline), is necessary to increase the compost pile acidity. One option Is to add coffee grounds.

5.5. ODOUR AND LEAHCED EVOLUTION AND CONTROL

Even though there is not any equipment available to measure odours, it remains a key parameter in the composting process. The own sense of our smell will indicate how well the process is being manged. Strong odours, such as putrid, rotting, or hydrogen sulphide (rotten egg smell), suggest that the compostinf is occuring under anaerobic conditions (PacWastePlus, 2022). Figure 19 shows the steps to diagnose the source of odours and provides guidelance on how to prevent them.

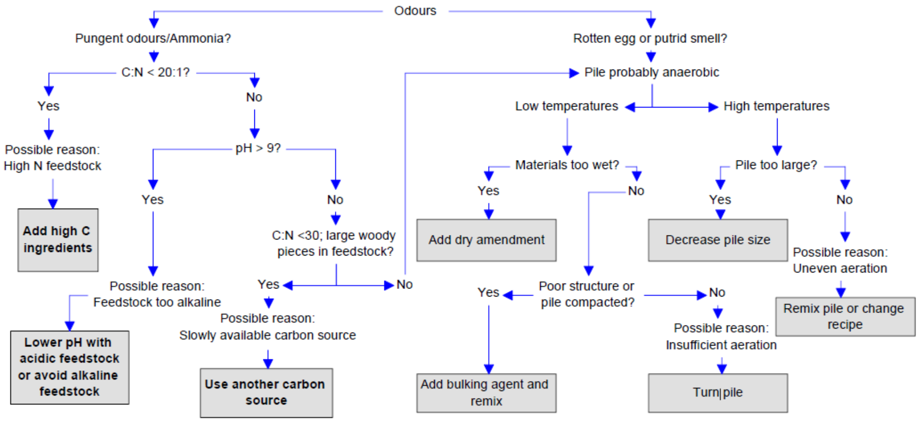

Figure 19.Flow-chart for diagnosing the source of odorous during composting. Source: PacWastePlus, 2022 taken from Wilkinson et al., 2001.

Leachate is the liquid that runs off from the composting pile, which is generated by organic matter. Leachate can be generated from (Waste Management Association of Australia National Technical Committee for Organics Recycling, 2004):

- Excess moisture in the raw materials.
- Release of water in the composting process.
- Infiltration of rainwater/stormwater.
- Excessive irrigation.

When leachate comes from fresh compost, it typically has a black colour, acidic pH and bad smell (Román et al., 2013). A management strategy must be developed to ensure that there is no risk to contaminate groundwater, surface waters or to cause odour problems. Leachate must be collected and stored. There are three alternatives for managing leachate (Agència de Residus de Catalunya (ARC), 2016):

1. Use them in irrigation during the decomposition stage, but always before a thermophilic sanitization phase.
2. Treat them in a treatment plant at the facility itself.
3. Transport them to external facilities that are authorized for the treatment of this waste.

In this study, leachate will be collected in a close deposit and will be used for irrigation if there is the need of rewetting. Alternatively, it will be treated with other effluents from the winery.

5.6. MADURATION AND STORAGE EVOLUTION AND CONTROL

The final stage involves the degradation of organic material through microbial activity. It is important to take under control temperature and aerobic conditions. Figure 9 and table 11 present the temperature at which microorganisms are exposed. Moreover, the processing phase is characterized by a reduction in weight and volume, partial stabilization and sanitization of the material, thanks to the maintenance of an optimal environment for the development of microorganisms (Agència de Residus de Catalunya (ACR), 2016).

The composting retention time depends on the feedstock, temperature, moisture and organic decomposition of the windrow. Westover 2006 and Burg et al., 2014, agree that composting grape marc, wine lees and grape stalks takes approximately 5 – 10 months.

The curing phase will take place in the covert. In this final stage, stable compost is generated. Oxygen consumption decreases, as well as energy and temperature. Because of the lower microbial activity, this phase is less critical than the previous stage. Even though, excessive temperature or excessive dryness can negatively affect the compost.

Once the pile’s temperature remains constant and at 60 – 65 ºC curing phase takes place. Windrows will be move inside the covert and temperature, pH and moisture will be controlled less frequently than during the composting process. Samples will be taken once the compost is set in the covert and a week after. All these parameters are going to be measured in two points: at windrow centre and at half-width of windrow. If the parameters measured in the two samples are similar, the compost shall be considered finished. If not, more samples might be taken and if the values are inconsistent, the compost must be moved outside the covert and continue composting in a windrow.

Characterizing the final product through a study is expensive and unaffordable for a small composting plant. Therefore, information from the existing literature can provide this information. Carmona et al., 2012 exposed a final compost characterisation. They composted grape pomace and grape stalks in a 1:1 ratio (v:v) in Seville (Spain) between 2,000 and 2,006. However, it argues that exists a high variability in the composition of some elements, which might result from the original composition of the fresh waste. This variability could be due to the specific handling of fresh waste in the wine industry and the soil, climate and agricultural characteristics of the region where the grapes originate from (Carmona et al., 2012). Due to this high variability, it is consulted another study of composting grape pomace and grape stalks from Pinto et al., 2023 where composting was carried out at Quinta da Torre, Portugal, from October 2021 to March 2022, using white wine waste from the Anselmo Mendes winery located in the Vinho Verde Region (NW of Portugal). Table 11 shows the results from both studies. Although the composition of the final compost differs from Carmona et al., 2012 and Pinto et al., 2023, it is assumed that considering these parameters might provide a good reference for establishing compost quality.

Table 11. Final compost quality parameters. Source: own elaboration. Information extracted from Carmona et al., 2012 and Pinto et al., 2023.

Elements	Carmona et al., 2012 results	Pinto et al., 2023 results
C	40 %	-
C/N [%]	17	21
OM (organic matter)	-	860 g/kg
N	2.35 %	22.8 g/kg
NH_4^+ - N	-	84.1 mg/kg
NO_3^- - N	-	239.7 mg/kg
P	0.39 %	4.3 g/kg
K	0.81 %	24.5 g/kg
Ca	2.70 %	6.7 g/kg
Mg	0.39%	2.3 g/kg
Na	0.02 %	-
Fe	4.017 mg/kg	-
Mn	127	-
Cu [mg/kg]	25	46.9
Zn [mg/kg]	41	21.8

B [mg/kg]	54	24
Pb [mg/kg]	-	0.27
Cd [mg/kg]	-	0.11
Cr [mg/kg]	-	1.85
Ni [mg/kg]	-	0.66
Hg [mg/kg]	-	0.003

The values from both studies are quite similar, despite the use of different units. Considering all these parameters, it can be concluded that the final compost should be free of any heavy metals or phytotoxic components. Furthermore, the compost is rich in C, N, K and organic matter substances, making it highly suitable for utilization as an organic amendment.

5.7. SUMMARY

Having considered the various parameters that need to be monitored, Table 12 shows a summary for effectively carrying out the monitoring and composting process.

Table 12. Summary of monitoring parameters, frequency samples and actions. Source: own elaboration.

Parameter	Frequency	Samples	Actions
Temperature	Twice a week for the first four weeks. Weekly thereafter.	At 6 different depths: 1. In the centre of the windrow. 2. At half height in depth on the middle of width's pile. 3. At 20 cm in height depth. 4. At 60 cm in height depth. 5. At 100 cm in height depth. 6. At 140 cm in height depth.	Temperature will stablish the composting phase. Mesophilic phase: 40 – 45 ºC. Thermophilic phase: 55 – 65 ºC. Pasteurization: 55 ºC. Curing phase: > 70ºC.
Moisture	Once a week	Representative sample: two different depths in three different equidistant points of length: 1. Sample extracted at windrow centre. 2. Sample extracted at half width of windrow	Low moisture → add water. High moisture → add more bulking agents such as wood chips.
pH	Twice a week for the first four weeks. Weekly thereafter.	Representative sample: two different depths in three different equidistant points of length: 1. Sample extracted at windrow centre. 2. Sample extracted at half width of windrow	pH < 5 →add drier feedstock. pH > 7 → add coffee grounds.
Odours	Always		Look at Figure 19.
Curing phase	Once the compost is set in the covert. A week after.	Representative sample: two different depths in three different equidistant points of length: 1. Sample extracted at windrow centre. 2. Sample extracted at half width of windrow	Constant values → compost curated and ready to use. Incoherent values → move the compost outside in a windrow and keep composting.

6. ESTIMATION OF INVESTMENT COSTS

Table 13 shows an estimation of the total plant investment costs. All the equipment required is shown in appendix 2 with its specifications technicals sheets.

Table 13. Estimation cost summary. Source: own elaboration.

Equipment	cost	
Shredder	730.52	€
Semi permeable cover	10,320	€
Self - propelled turner	80,000	€
Leached deposit	929.9	€
Concrete pavement floor	8,000	€
Bricks	54	€
Corrugate steel panels	600	€
Thermometer	224.1	€
Balance	99	€
Drying oven	269	€
pH meter	100	€
Workers	400	€
TOTAL	***101,726.52***	***€***

Threfore, the implementation of this composting plant design costs approximately 100,000€. Moreover, it is necessary to hire a team of workers to ensure a proper composting development.

7. CONCLUSIONS

Based on this study, the specific objectives have led to the following conclusions:

- The generation of waste during winemaking mainly consists of grape stalks, grape pomace and wine lees. These by-products are a source of bioactive compounds represented by polyphenols and dietary fiber, making them valuable resources for different industries including agriculture, food, cosmetics, bioenergy, pharmaceuticals, medicine, chemistry, textiles, and winemaking.
- There are several advanced and sustainable extraction techniques that show great promise for extracting biocomponents from these by-products. Unfortunately, further research is needed to determine the limitations, including extraction cost, recovery time, stability, toxicity and percentage of purity.
- After reviewing the existing literature on the topic, this study has chosen composting as the most appropriate treatment for managing winery waste in a small-medium cellar.
- The composting phase will involve the use of six windrows measuring 25 m x 4 m x 2 m (LxWxH) and covered with a semi-permeable material. T the final stage, known as the curing phase, will take place in a structure consisting of three bays with dimensions of 6 m x 18 m x 4 m (LxWxH). Overall, the composting plant will occupy an area of 45 m x 27 m, requiring approximately 1,200 m^2 of surface area.
- With an investment of 100,000 €, it is feasible to implement a viable valorising treatment for a small-scale winemaking activity.

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TABLE LIST

FIGURE LIST

APPENDIX

APPENDIX 1: VALORISATION BY-PRODUCTS

1.1. Grape pruning

Grape stalks, about 7%, w/w of grape total weight (Troilo et al., 2023), are usually removed before the fermentation phase to avoid excessive wine astringency. They are a source of phenolic compounds such as tannins, flavan-3-ols, hydroxycinnamic acids, monomeric and oligomeric flavonols, stilbenes and lignocellulosic compounds such as hemicellulose, cellulose, and lignin.

The agronomic practice of pruning generates an enormous quantity of agricultural wastes, principally vine shoots, with a production estimated per year of about 1–2 tonnes per hectare (Troilo et al., 2023). They are usually shredded and used as a soil conditioner, to improve fertility, or as biomass to produce energy. More recently, they have been used as a source of bioactive compounds (dietary fibers, phenols, proteins, lipids, hydrocolloids) for food, pharmaceutical and cosmetic industries, due to the nutritional benefits.

Grape leaves, due to their presence of organic acids, lipids, and polyphenols, can be used in the cosmetics industry.

1.2. Grape pomace

Pomace is a real treasure because during winemaking process part of phytochemicals remains in grape and not into the wine. The resulted pomace is a source of phenolic compounds: 9 kg per tonne (Troilo et al.,2021). The amount quantity of resveratrol, a stilbene phenolic component, is what makes valuable this by-product. Its high values of phytocomponents makes a wide range of possibilities in diverse industries such as biorefinery, agricultural, pharmaceutical, alimentary, among others. Also, grape pomace involves different parts of grape which contribute to develop a wide-ranging product.

Moreover, possess a significant benefit for human health presenting anti-inflammatory, antioxidant, antimicrobial, antiviral, anti-cancer, neuroprotective, cardioprotective and hepatoprotective actions. It is found that grape pomace can reduce arrythmias in a high-fat-fructose (HFF) diet (Perdicaro et al., 2017).

For example, seeds are rich in antioxidant compounds, such as vitamin E and phenolic compounds, phytosterols, fibers, proteins, carbohydrates, and minerals, but especially in lipids (Troilo et al., 2021). Grape skin and pulp, instead, are a rich source of fibers and phenolic compounds including gallic, vanillic, and caftaric acid; flavonols such as quercetin, myricetin, and kaempferol; and anthocyanins, whose presence is closely dependent on the vinification procedures and grape variety considered.

The design for treating grape pomace in special places follows the following procedure. Firstly, the alcohol and tartrates are recovered. Then, the pomace is dried, and the skins and seeds are separated. From the dried skins, it is possible to produce animal feed and skin byproducts. As for the seeds, if they are dried, grape seed oil and grape seed extract can be obtained. Additionally, if the seeds are pressed, a source of energy in the form of biodiesel or bioethanol can be acquired. A comprehensive description of the resulting products is provided below:

- Alcohol: Approximately 3 liters of alcohol and 1.5 kilograms of tannin can be obtained from every 100 kilograms of pomace.
- Grape seed tannin: Widely used in the wine industry for clarification purposes, as an antioxidant, and to stabilize color. It has the ability to improve both the structure and the aging potential of wine. Grape seed tannin is also rich in proanthocyanidins and can be taken as a nutraceutical supplement in capsule form due to its antioxidant and free radical scavenging properties (known as Brenn-O-Kem).
- Grape seed oil: After refining, grape seed oil can be utilized in pharmacology, cosmetology, and the food industry.
- Grape seed extract (GSE): This is an extremely powerful antioxidant with numerous health benefits. Antioxidants are bioactive compounds derived from plants that have a significant impact on both aging and disease prevention. Grape seed extract can also be employed as grape seed tannins to enhance the quality of wine (Brenn-O-Kem).

Solid product from distillation can be used as a feedstock of biochar production. Biochar is a carbon-rich material derived from the decomposition of organic matter at high temperature in an oxygen deficient environment (Lehmann and Joseph 2009). To produce biochar for agricultural amendment is necessary to do a thermal process: pyrolysis at a 450ºC. It is seen that its properties can improve soil quality. Is characterized for having a high organic carbon content, high mineral content, low ash, low volatile matter contents, porous structure, high surface area and high pH value. In addition, it has shown multiple benefits related to agriculture such as increased plant growth and crop productivity or protecting plants against abiotic and biotic stress (for example root-knot nematode).

Otherwise, it can be a good idea to make pellets instead of biochar. Pellet combustion with grape pomace led to higher calorific values with lower debonding temperature (Miranda et al. 2011). In contrast to pyrolysis, combustion is exothermic. Combustion and co-combustion with lignite can offer better combustion characteristics and reduce the use of lignite (Energy, Ecology and Environment, 2023).

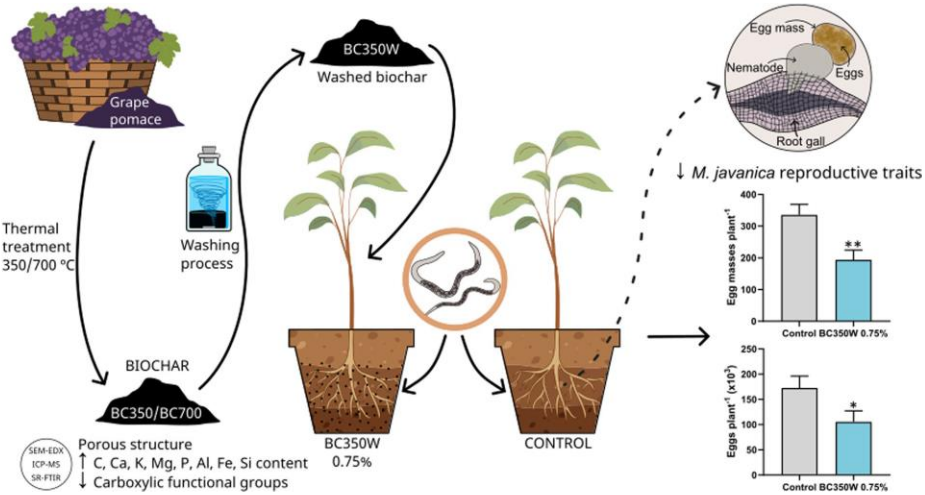

Figure 1.2.A. Diagram of biochar production from grape pomace waste and its application as a soil amendment. Source: Martínez-Gómez et al. Biochar,2023.

Food colorant, E163, is another interesting application. Is obtained from red wine grape pomace due to its rich colour. This colour comes from anthocyanins, a class of red-, purple-, and blue- pigmented flavonoids. Though much of the anthocyanin content of red wine grapes is imparted into the wine itself, a considerable portion, about ten percent, is retained in the pomace (J. Agric. Food Chem. 2018).

Livestock animal is one more application of grape pomace. Specially, grape bunches are rich in polyunsaturated fatty acids (PUFA) such as linoleic acid. Thus, can be good for feed additives in animal nutrition.

Grape pomace can be used for environmental remediation in soil suspension. It is a bioremediation of chloroethene-contaminated soil. Chloroethenes such as tetrachloroethene

(PCE) and trichloroethene (TCE) are widely used as solvent in the metal industry and the dry-cleaning industry. Lamentaly, their spillage into soil and groundwater due to improper handling has negatively impacted human health (Ohashi et al. Bioresources and Bioprocessing, 2023). The attempt it to use wine pomace to treat toxic substances by converting it into porous carbon to adsorb heavy metals in wastewater (Nayak et al. 2016). Carboxylic acids from pomace such as L-lactic and L-tartaric acid operate as hydrogen donors in the anaerobic microbial degradation of chloroethene.

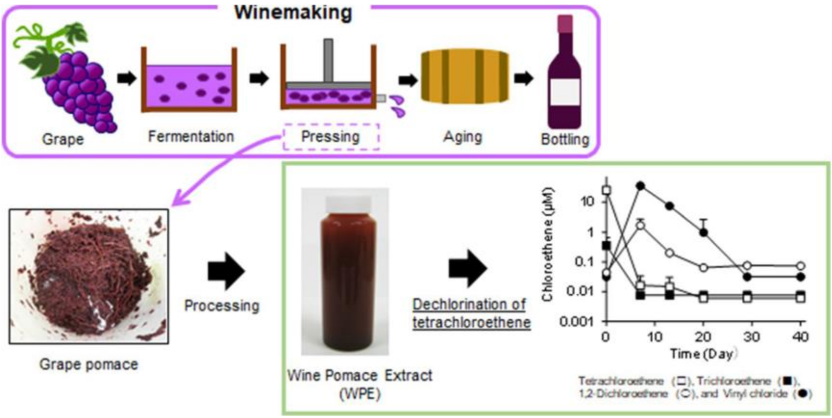

Figure 1.2.B. Graphical scheme of a bioremediation of chloroethene-contaminated soil using grape pomace waste. Source: Ohashi et al. Bioresources and Bioprocessing, 2023.

1.3. Wine lees

Wine lees or vinasses are defined as the residue formed at the bottom of the container during the wine fermentation stage. It consists of a solid phase, looks like sludge, composed of yeasts and bacteria responsible for vinification. About 5 % w/w of total grape weigh are lees (Troilo et al., 2023). It mainly contains ethanol, tartaric acid, phenolic compounds and yeast cells. In general, wine lees, despite being a material rich in polyphenols, are underused or discarded (Andrade Bulos et al. Food Production, Processing and Nutrition, 2023).

Wine lees represent a precious by-product linked to the presence of insoluble carbohydrates (from cellulosic and hemicellulosic fractions), phenolic compounds, and lignin, but especially proteins, which make wine lees nutritionally very rich. It is considered a raw source for phenolic compounds extraction due to the ability of yeasts used during the fermentation process to interact with phenolic compounds and adsorb them (Jara-Palacios 2019; Mena et al. 2014). Figure XX exposes the main phenolic compounds. Source: Bulos et al., 2023.

Lees are used in oenology due to the influence of coloring and organoleptic characteristics. As well, it has a high relevance in wine aging in the amplification of aromatic compounds and reducing astringency and bitterness. Another used is for recovering tartaric acid, which consists of drying, grinding and diluting the wine lees with potassium bicarbonate in hot water.

Also is used in alimentary industry. For example, it is use as a natural additive for meat. It has been tested in deer burgers as a substitute of sodium ascorbate. Lees provide a higher antioxidant capacity and phenolic content than sodium ascorbate. This fact results in a higher protection against lipid and protein oxidation of burgers during the storage in modified atmosphere packaging (MAP).

One more application in alimentary industry is the used of wine lees as a natural antioxidant with added value to improve the rheological properties of ice creams. It also enhances homogenization of ice cream. Using wine lees in ice cream showed a decrease in pH, firmness, lightness, and the amount of freezable water, as well as an increase in viscosity and fat destabilization. Furthermore, the ice creams with wine lees showed satisfactory concentrations of anthocyanins and phenolic compounds (Hwang et al. 2009).

As well as grape pomace, wine lees are rich in polyphenols, especially anthocyanins. Due to this, it can be applied for cosmetic formulation in order to promote the health of human skin: whitening and antiaging.

A sample of bioenergy industry is that wine lees can be used to produce poly-3-hydroxybutyrate (P3HB) by bacterial strain Cupriavidus necator DSM 7237. P3HB is a polyester known as renewable, biodegradable and biocompatible substitute for conventional non-degradable plastics.

APPENDIX 2: TECHNICAL MACHINERY SHEETS

2.1. Shredder: WoodChipper technical sheet.

Table 2.1.A. Shredder specifications, technical sheet. Source: own elaboration, [12].

Specifications	Values
Brand	T-Mech
Model	24308
Engine brand	Ducar
Product line	MonsterShop
Power source	Petrol
Fuel volume	6,5 L
Engine type	4 – stroke
Horsepower	15 HP
Tank capacity	6.5 L
Cutting capacity	102 mm
Height	134 cm
Width	64 cm
Engine size	420 cm^3
Oil type	0w – 30 Non-Synthetic Engine Oil
Oil volume	0.6L / 1.1L
Blade speed	2400rpm (max. output 3600rpm)
Material	Steel
Features	FREE Tool Kit, FREE Safety Equipment
Colour	Blue
Cost	***730,52 €***

2.2. Semi-permeable covers comparison technical sheet.

Table 2.2.A. Semi permeable cover specifications comparative. Source: own elaboration, [14] and [15].

Specifications	First type	Second type
Principal characteristics	Antistatic, Water Soluble, Waterproof, Windproof	Waterproof, Anti-odor, Abrasion-resistant, Tear-resistant, Organic, Windproof
Material	PTFE[a] composting nylon fabric cover	PTFE composting polyester fabric cover
Weight	Customizable	Customizable
Thickness	Middleweight	-
Technics	Tissue	Tissue
Type	PTFE	PTFE
Width	Customizable	Customizable
Density	Customizable	Customizable
Coating type	Laminated HDPE (high density polyethylene)	PU (polyurethane)
Colour	Customizable	Black
Waterproof	20,000 mm	20,000 mm
Permeability	500 g/m^2. 24h	10,000 g/m^2.24h
Construction	3 – layer laminated	3 – layer laminated
Middle layer	PTFE membrane	PTFE membrane
Method lamination	Hot melt diffusion	Hot melt
Backing layer	100 % tricot nylon	100 % tricot polyester
Origin place	Zhejiang China (mainland)	Zhejiang China (mainland)
Brand name	DENTIK Membrane	DENTIK Membrane
Certification	RoHS	-
Meter price	**6.58 €**	**8.60 €**
Total cost	***7,896 €***	***10,320 €***

2.3. Self – propelled turner machine technical sheet.

Table 2.3.A. Self - propelled turner specifications and technical sheet. Source: own elaboration, [17].

Specifications	Values
Brand	Menart
Model	SPM – 47
Motor Power	225 kW / 302 hp (St. V) 205 kW / 275 hp (Tier3)
Capacity	3,000 m³/h
Maxim pile width	4.9 m
Maxim pile height	2.4 m
Tunnel height	1.9 m
Cost	***80,000 €***

2.4. Leached deposit technical sheet.

Table 2.4.A. Leachate deposit specifications and technical sheet. Source: own elaboration, [19].

Specifications	Values
Tank model	TH – 3000
Max. diameter [mm]	1,440
Inspection opening [mm]	350
Height [mm]	1,570
Capacity [L]	2,800
Cost	***929.90 €***

2.5. Concrete pavement floor.

Table 2.5.A. Concrete pavement floor specifications and technical sheet. Source: own elaboration,[21].

Specifications	Values
Brand	Axton
Size	25 kg
Colour	Withe
Time before can be use	1 day
Stting time	6 hours
Product type	Waterproof
Cost per unit	25 €/25 kg
Nº units	320 units
Total Cost	***8,000 €***

2.6. Covert. Covert walls are going to be constructed with bricks and for the roof is going to use corrugate steel panels.

Table 2.6.A. Bricks specifications. Source: own elaboration, [22].

Specifications	Values
Brand	Double hollow brick
Size	240 x 80 x 112 mm
Cost per unit	27 € / 100 units
Nº units	2 unit
Total Cost	***54 €***

Table 2.6.B. Roof made of corrugate steel panels specifications. Source: own elaboration, [23].

Specifications	Values
Brand	VidaXL
Size	36 x 100 cm
Cost per unit	60 € / 12 units
Nº units	120 unit
Total Cost	***600 €***

2.7. Controlling devices

Table 2.7.A. Thermometer specifications and technical sheet. Source: own elaboration, [24].

Specifications	Values
Brand	Greisinger
Model	G 1720
Temperature range	-70 – 250 ºC
Accuracy (device with fixed sensor)	-20 – 100 ºC ± 0,1 K ± 1 digit -70 – 250 ºC ± 0,2% of measured value ± 2 digits
Operating conditions for the device	-20 – 50 ºC. 0 – 95% relative humidity (non-condensing) temporarily usable up to 100% relative humidity.
Display / Backlighting	3 – line unit with background light, protected by an unbreakable pane, overhead display at the push of a button.
Power supply	2 x AA battery, aprox. 5,000 h operating time.
Protection ratting	IP65/IP67 (with devices with BNC connection only with sensors with waterproof connection)
Housing	Break – proof ABS housing
Dimensions without the sensor connection	108 x 54 x 28 mm
Weight without the sensor	130 g
Connection	BNC socket: for interchangeable sensos.
Sensor	Durable insertion sensor
Diameter sensor	3 mm
Material sensor	Pt 1000 2 – wire
Sensor longitude	1 m
Cost	***112.05 € (x2)***

To measure moisture content a balance and a drying over are the required equipment.

Table 2.7.B. Balance specifications and technical sheet. Source: own elaboration, [25].

Specifications	Values
Brand	Accurex
Model	DSX – 3
Capacity	3,000 g
Resolution [a]	0.1 g
Response time	2 s
Weighing units	kg and Ib
Feed	Network 220V 50 Hz
Working temperature	0ºC / + 40ºC
Material structure	ABS and stainless steel
Load sensors	Aluminum cell
Diameter of weighing plate	295 x 230 mm
External dimensions	300 x 345 x 107 mm
Weight	3 kg
Cost	***99 €***

Table 2.7.C. Laboratory drying oven specifications and technical sheet. Source: own elaboration, [26].

Specifications	**Values**
Brand	Steinberg Systems
Model	SBS-LI-8
Capacity	7.5 L
Power	300 W
Strain	230 V
Temperature	5 ºC (room temperature) – 45 ºC
Temperature fluctuation	± 1.5 ºC
Timer – duration	0 – 9.999 min
Material	Steel (Q235), stainless steel (SS 201), organic silicon, aluminum, rock wool
Dimensions	30 x 33 x 33 cm
Internal dimensions	20 x 16 x 23 cm
Weight	7.8 kg
PID automatic tuning	Yes
Over temperature alarm	Incorporated
Cost	***269 €***

Table 2.7.D. pH meter specifications and technical sheet. Source: own elaboration, [27].

Specifications	**Values**
Model	pH 220
Fabricant	HIBOK
Measurement range	0.00 – 14.00 pH
Precision	0.01 pH/ ± 0.2 pH
Response time	0.8 ms
Calibration	Automatic
Temperature compensation	Automatic
Electrode connection	BNC
Points calibration	pH 4, pH7 or pH10
Normative	CE
Source battery	4 bat. 1.5 V (AAA)
Dimensions	180 x 40 x 32 mm
Electrode dimensions	9.5 diam. X 120 mm
Cable length	1.5 m
Weight	220 g
Accessories included	pH electrode, pH4/pH7 standard solutions, battery and instructions
Cost	***100 €***